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Professor J. McKeen Cattell, M.A., Ph.D.

AND

F. E. Beddard, M.A., F.R.S.

VOLCANOES


GPP

Plate I. Vesuvius in Eruption, 1872.

VOLCANOES

THEIR STRUCTURE AND SIGNIFICANCE

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BY

T. G. BONNEY, D.Sc., LL.D., F.R.S.

PROFESSOR OF GEOLOGY AT UNIVERSITY COLLEGE, LONDON

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PREFACE

WERE it not that Nature sometimes supplies new material, there would be little excuse for another book on Volcanoes. The treatises of Daubeny and Scrope (to speak only of those in English) are not yet superannuated; the concise volume contributed by Professor Judd to the International Scientific Series is only seventeen years old; and while these chapters were being written Sir A. Geikie's work on British Volcanoes, and Professor I. C. Russell's on those of North America, made their appearance. The last two, however, are more or less restricted to special topics, and some eruptions of exceptional importance have occurred during the last twenty years, so that I have ventured to increase the literature on this interesting and, in some respects, very difficult subject.

In writing this book, I have endeavoured to lead the reader through descriptions of the varied phenomena of volcanic action, in the present and in the past, towards ascertaining by inference the cause or causes of eruptions. For this reason I began by an account of the "living volcano," choosing instances which may exhibit it (to continue the metaphor) at every stage

from birth to death. Next, after some preliminary explanations of certain technicalities, I conduct the reader to the dissecting theatre, and point out what may be discovered in this method of study. I then recount the geological history of volcanoes in a single country, with the view of bringing out the changes in the position of vents, and in the nature of the ejected materials; and, lastly, I describe the distribution of volcanoes either at present or in comparatively recent geological times, in the hope of finding something suggested by their geographical position and modes of occurrence. In the last chapter I sum up the results to which our investigations have apparently pointed, and endeavour to ascertain the conclusions to which they lead. At the end of this the reader, I fear, will, not unreasonably, complain that he has gone through much and got to little, for I am unable to provide him with any complete theory of vulcanicity. We are, I think, in this position: We have ascertained a number of important facts; many of these suggest conclusions, but some of the latter seem at present difficult to reconcile and harmonise. Indeed, it is my opinion that either some link in the chain of evidence still remains to be discovered, or the relation of those which we know is not yet fully understood. In other words, we do not seem to be in a position to put forward a complete explanation of vulcanicity. Nevertheless, I am sanguine that, to borrow an appropriate phrase from a child's game, "we are getting warm," and that our successors, by

the end of the first quarter of the coming century, will have got much nearer to the solution of the problem.

The plan which I have adopted has occasionally brought about some slight repetition. From this I have not shrunk, for the average reader prefers, I think, reading on continuously, to turning back in order to refresh his memory. This plan also has obliged me occasionally to use a somewhat technical term before I have reached the place where it would naturally be explained. This difficulty I have tried to overcome by the aid of a short glossary. If I were writing a formal text-book, I should begin with a number of definitions; but when these come first, they prove anything but a whet to the appetite of the ordinary reader, even if scientifically inclined, and such a one it is whom I have kept in view. In his interest I have avoided, as far as possible, all technical terms. Indeed, I must ask critics to remember that my aim in writing has not been the examination-room. They will, I fear, detect mistakes; for these I ask pardon in advance. *Humanum est errare*, both in authors and in printers. They will doubtless be able to suggest improvements. That these might be made I am fully conscious, for I am an unnatural father, and when my literary offspring go forth into the world, I feel little disposition to dismiss them with a blessing.

Turning, in conclusion, to a more grateful task, I have to express my thanks to friends for aid of

various kinds. To the Rev. E. Hill for kindly reading the proof of the last chapter, and making valuable suggestions thereon; to Professor Judd, on whose book I have more than once freely drawn; to the Council of the Royal Society for Figures 4 and 5; to that of the Geological Society for Figures 8, 9, and 17; to Messrs. Cassell for Figures 1 and 3, which appeared in *The Story of our Planet;* and to Sir A. Geikie for kindly lending me Figures 13 and 15, which came from his *Ancient Volcanoes of Great Britain.* I have to thank my old pupil, Mr. A. S. Reid, for the photograph which has been reproduced on Plate XII., and am deeply indebted to Dr. Tempest Anderson for those which appear on Plates VIII., IX., and X. His collection of photographic studies, taken with his own hand, of volcanic phenomena, is, I believe, unequalled in Britain, and I hope some day he will publish a selection of them, with a descriptive text. Such a volume would be a great boon to students.

T. G. B.

LONDON,
November, 1898.

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PLATE

(4) Elbruz, from the highest rocks (about 17,500 feet), collected by Mr. Horace Walker. Ground-mass as before, but more transparent, because of diminished quantity of iron oxide. The larger grains represent plagioclase felspar (north-west corner), hornblende (north-east corner), and biotite (just to south-west of the latter).

All four in my cabinet.

(1) Mass of basalt, with curved cross-joints to pillars in foreground. At the back another mass of basalt, showing the outlines assumed under erosion by these old flows, which formerly obtained for them the name of trap.

(2) Columns and curved cross-joints.

From photographs by Dr. Tempest Anderson.

In the foreground is part of the crater of the Puy du Pariou, its edge running across the picture. Above this, on the left, is the crater of the Puy des Goules, and overlapping this comes the flattened dome of the Grand Sarcouy. On the right is the Puy de Chaumont, a large cone with a partially effaced crater, and behind it the Puy Rugère. Photograph by Dr. Tempest Anderson.

This is an example of one of the minor cones and craters which are abundant in a "Puy" district or on the flanks of a larger volcano.

(2) CONE BREACHED BY LAVA-FLOW, LAS PALMAS, GRAND CANARY.

The spectator looks up the lava stream (which comes to the foreground on the right-hand side) into the crater. This is practically identical with the breached cones in Auvergne, described at page 102. Photographs by Dr. Tempest Anderson.

VOLCANOES

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CHAPTER I

THE LIFE-HISTORY OF VOLCANOES

WHAT is a volcano, and by what is it caused? As most persons of ordinary education have a general idea of the meaning of the term, we may be aided in any attempt to answer the latter clause of the question, if we gradually work up to our definition by describing in some detail the physical features and the phenomena which are generally associated with the word volcanic.

Let us transport ourselves in imagination to a period rather more than eighteen centuries ago—the year, for instance, of the destruction of Jerusalem—and to the Bay of Naples. Let us view the scene from the deck of a vessel which is too far away from land for us to distinguish whether the buildings be classic or mediæval or modern. Villas seem mere specks, villages and towns only pale blurs and streaks on the hillslope or by the waterside. The larger of these occupy positions much the same as they still

do. To the left hand of the longest and most important mass of buildings the hills seem to present the familiar outlines. To the right a mountain rises, as it still does, but this looks very different from the modern Vesuvius. The huge cone, in which the steaming mass now culminates, the long broken wall

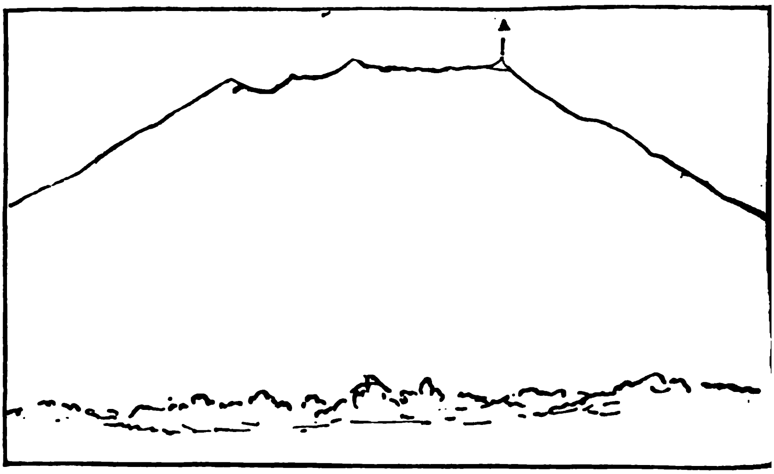


FIG. 1. ROUGH SKETCH OF VESUVIUS FROM THE NORTH.
Showing the crest of Somma, the top of the present cone projecting at A. This must represent the general outline of the volcano prior to A.D. 79.

on its left, which at the present time is so conspicuous and peculiar a feature, are not to be seen, but they are replaced by a broad and almost level crest nearly at the same elevation. This is the margin of a wide crater, probably about 1200 feet in depth,[1] like those of Astroni and the Solfatara, but on a grander scale, and it crowns a conical hill, which rises rather

[1] Phillips, *Vesuvius*, p. 185.

more than 3700 feet above the sea, instead of having the floor of its crater, as is the case with them, but little above that level. If we imagine ourselves standing on this floor we find it enclosed on all sides by steep cliffs, composed of scoria and hardened dust, of streamlets or dykes of lava, which, however, are festooned with wild vines and other climbing plants. The floor is also a confused mass of scoria and blocks of lava, but this is almost hidden by the luxuriant vegetation. Beyond all doubt we are standing in the crater of a volcano, but it shows no trace of any recent eruption, and we find on enquiry that no memory of any such catastrophe survives in the traditions of the district.

In a brief outline this is what occurred a few years later than the time of which we have been speaking, namely, in the summer of the year 79 of the present era. The long repose of centuries was broken, the imprisoned giant, after one or two preliminary stirrings, awoke from slumber. This epoch began with a series of earthquakes, which increased in frequency and severity till at last a new and strange cloud appeared on, or rather rose up from, the summit of Vesuvius.[1] Dark as the blackest fog of London, it shot up like a pillar, and then spread out on all sides till it formed a rude and gigantic presentment of one of the stone-pines which still grow upon the Campanian hills. This, however, was but a hoisting of the flag of battle. While the land rocked

[1] It was about one o'clock in the afternoon of August 24th, A.D. 79.

like the sea, while the sea itself broke and ebbed and flowed on the coast in tides as novel as they were eccentric, explosion succeeded explosion, roar followed roar from the top of the mountain. This had now been lost to view under a canopy of black clouds, from which flashes of lightning darted. The light of the afternoon faded as the mirky pall spread farther from its centre. Soon bits of cellular scoria began to fall in pattering showers, and heavier blocks of lava came dropping down like stones from the catapults of ancient warfare. Some still glowed as they fell; fragments of rock also, dislodged by the incessant shocks of earthquake, came rolling down the mountain-side. When the sun had set, the cloud which veiled the summit was lit up, not only with the intermittent flashes of lightning, but also with a continuous ruddy glow, as from some vast hidden furnace, while the hail of projectiles became thicker and heavier. So passed the night. Then came the hour of dawn, but not the light of day. This, we are told, even at Misenum, some six leagues away from the crater, was "exceedingly faint and languid." But the terrors of the eruption were not yet ended. Near to that town the level ground, on which the fugitives from the shaken houses had gathered, rocked to and fro; the sea rolled back from the land; the cloud that rested on Vesuvius became more and more mirky, and then seemed to be riven by darting sheets of flame. Presently it came sweeping across the bay, and an awful darkness settled down upon Misenum.

It was blacker than any night, "like that of a room shut up." Through this fearful gloom ashes fell in thick showers, so that when at last the cloud slowly rolled away, and the pale day gleamed out, the ground was white as if with a deep snow. The worst was now over, but the full extent of the disaster had yet to be learned. The aspect of Vesuvius had been marvellously changed; the northern half of its crater-wall still remained, but the southern had been blown completely away.[1] Herculaneum, at the foot of the mountain, was stifled under a torrent of mud, many yards thick,[2] which had rolled down the slopes. Pompeii, which is more distant in a south-easterly direction, was buried beneath a layer of volcanic ash three or four yards in depth. Stabiæ, though ten miles away from the crater, was partly overwhelmed by similar materials. Thousands of acres had been changed from fertile lands to wastes of barren pumice; vineyards, orchards, forests, were blasted, houses were in ruins, hundreds of lives had been lost. So ended the first eruption of Vesuvius of which any record is preserved in history.

The phase of activity on which the mountain entered in the first century has continued ever since, though there have been intervals of quietness, sometimes comparatively long. So far as we can ascertain,

[1] No lava seems to have been emitted in this eruption, and if a central cone was formed it was probably insignificant in size.

[2] It consists of the finer volcanic *débris*, which no doubt was swept down by torrents formed by the condensed steam. The layer is sometimes seventy feet thick, but probably the upper part of the mass is of a later date.

actual eruptions during the first thousand years happened once or twice in a century, and for nearly four hundred years prior to 1631 only two or three, at most, seem to have occurred. During the last long pause herbage sprang up, thickets and copses grew on the floor of the crater. Then came another awakening. It was heralded, as before, by six months of earthquakes. It began with terrific noises in the interior of the mountain. The verdure vanished, the wide crater became full, and then, on the morning of December 16, 1631, the actual eruption commenced. Once more a huge column of dust and steam rose up from the summit of Vesuvius, spreading out into the form of a pine tree, and the finely powdered rock was borne by the winds more than a hundred miles away. But then a new horror was added to those of the first eruption. Over the broken lip of the crater the molten lava poured in broad streams, which divided as they swept rapidly down the mountain-side. "It reached the seacoast at twelve or thirteen points . . . the length of some of the streams of lava was five miles, and the interval between their extremities seven and a half."[1]

Again there was great destruction both of property and of life. Resina, Granatello, and Torre del Greco were more or less overwhelmed by the lava torrents, and it is said that 18000 persons perished. No small part of this frightful loss of life was due to the unwisdom of the governor of the last-named town,

[1] Phillips, *Vesuvius*, p. 47.

who prevented the people from quitting the place till too late. The lava was already at the walls when the order for departure was given; it burst through these into the crowded streets, bringing to numbers an awful death and an unknown grave. Since this eruption Vesuvius has never been really at rest, though more than a century passed before the occurrence of one on an exceptionally large scale. The discharges just described appear to have cleared out the great broken crater, and the process was repeated in the summer of 1660 by an eruption which left a huge and deep yawning gulf in the interior. A marked change in the outline of the mountain appears to have been wrought by an eruption in the autumn of 1685, for it built up a central cone, which, though inferior in size to the present one, was large enough to be visible from Naples. This was augmented by eruptions during the next thirty years, until, in 1717, Vesuvius presented nearly the same general form as it still does. The eighteenth century was signalised by repeated eruptions, and those between 1764 and 1779 were carefully observed and recorded by Sir William Hamilton, British Ambassador at the Court of Naples. Two points in his description are of especial interest, one referring to the changes which occurred in the central cone; the other to the actual outbreak of a great lava-flood of which he was a witness. The former will be readily understood by reference to the annexed diagram, which is copied from one given by Sir W.

Hamilton. Prior to 1767 a small cone had been built up within the crater of that mentioned above. By successive eruptions of scoria and lava the two were blended into one, so that, finally, as may be seen in the last diagram, the complete cone rose about 200 feet higher than either did at the

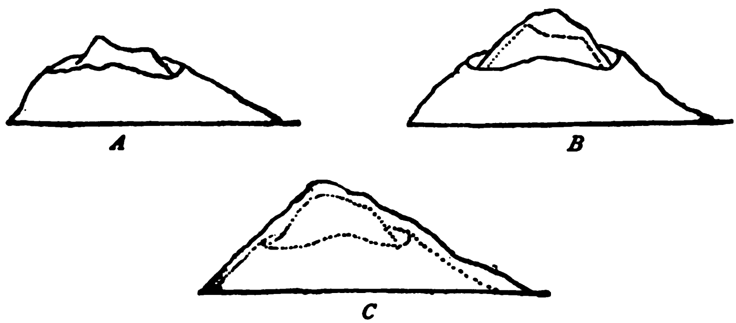


FIG. 2. STAGES IN THE GROWTH OF THE CONE OF VESUVIUS IN 1767.
(After Sir W. Hamilton.)
A, state on July 8, 1769; *B*, October 18th (day before eruption); *C*, October 29th.

beginning. The other matter—the outbreak of lava—occurred during the eruption of 1767. Throughout the summer the volcano had been active, throwing out dust, scoria, and even heavy bombs. Lava was discharged during August and September, which began on the 12th of the latter month to flow down the mountain-side. Stones also were shot up into the air to a height of a thousand or even sixteen hundred feet. This lava stopped flowing on the 18th of October, but broke out at a new place on the side of the cone on the following day. As there was a lull in the discharges of *débris*, and the lava was issuing quietly,

Sir W. Hamilton ascended the mountain in order to obtain a nearer view. He had reached the Atrio del Cavallo, as the space is called between the foot of the cliffs of Somma and the slope of the central cone, and was engaged in making observations on the lava, when (to quote his own words) "on a sudden, about noon, I heard a violent noise within the mountain, and at the spot C,[1] about a quarter of a mile off the place where I stood, the mountain split; and with much noise from this new mouth a fountain of liquid fire shot up many feet high, and then like a torrent rolled on directly towards us. The earth shook at the same time that a volley of pumice stones fell thick upon us. In an instant clouds of black smoke and ashes caused almost a total darkness; the explosions from the top of the mountain were much louder than any thunder I ever heard, and the smell of the sulphur was very offensive. My guide, alarmed, took to his heels, and I must confess that I was not at my ease. I followed close, and we ran nearly three miles without stopping. As the earth continued to shake under our feet I was apprehensive of the opening of a fresh mouth, which might have cut off our retreat. I also feared that the violent explosions would detach some of the rocks off the mountain of Somma, under which we were obliged to pass; besides, the pumice stones, falling upon us like hail, were of such a size as to cause a disagreeable sensation upon the part where they fell."

[1] Indicated on a diagram given in a tract entitled *Observations on Mount Vesuvius, etc.* (1772), from which this extract is taken (page 26).

On returning in safety to his villa, which was near Portici, Sir W. Hamilton found his family in great alarm from "the continual and violent explosions of the volcano, which shook the house to its very foundation, the doors and windows swinging upon their hinges."

Leaving for the present the history of Vesuvius, we pass on to a cone in the same region, which, though on a comparatively small scale, tells us the whole story of its building, for its active life numbered but a few days. This is Monte Nuovo in the Phlegræan Fields, the beginning and growth of which have been duly recorded by eye-witnesses. The site of the cone, prior to the year 1538, formed a shallow part of the Lucrine Lake, itself the breached crater of a very ancient volcano. This, in classic times, was a harbour for the galleys of the Roman fleet, but since then it has been almost filled up by the new outburst. For about two years prior to this event the district had been disturbed by earthquakes, which, on the 27th and 28th of September, became almost continuous at Puzzuoli. During these the low shore between Lake Avernus, Monte Barbaro,[1] and the sea was slightly elevated, so that the water retreated, leaving bare a strip about two hundred paces in width. The surface cracked, steam escaped, and at last, early on the morning of the 29th, a greater rent was made, from which "were

[1] Both old craters, the former supposed in classic times to be the portal of the nether world.

vomited furiously smoke, fire, stones, and mud composed of ashes, making at the time of its opening a noise like the loudest thunder." Some of the stones "were larger than an ox." The mud was of the colour of ashes and at first very liquid, becoming less so after a time. The stones, many of which were cellular, were shot up into the air "about as high as a cross-bow can carry, and they fell down

FIG. 3.

sometimes on the edge, sometimes into the mouth itself." The ejected material in less than twelve hours built up a hill which was not much smaller than the present one. But some of the muddy stuff travelled for considerable distances; it covered Puzzuoli and the neighbouring country, and it even plastered and defaced many of the palaces in Naples.[1] The eruption ceased on the third day, and several persons ascended the newly formed hill and looked down

[1] About eight miles distant.

[redacted]

into the crater. This, as the observer writes, "was a round cavity, about a quarter of a mile in circumference, in the middle of which the stones which had fallen were boiling up, just as a cauldron of water boils on the fire." The eruption was renewed on the fourth day and again on the seventh: on the latter occasion so suddenly that several persons who were on the hill were killed by the falling stones, or were suffocated by the mephitic vapours. The ejection of "smoke" continued for some time, and a glow was visible at night, but every sign of activity has long since disappeared. "The cone is formed of a yellowish grey, rather compact scoria, something like badly burnt Cambridge brick, but here and there darker fragments occur. This is not generally very vesicular, and at times is soft and decomposed. The slope of the cone is rather steep, and it is clothed with coarse herbage and such plants as heath and broom, together with scrub-oak and ilex, arbutus, mulberry, and stone-pine. The eastern lip of the crater is considerably higher than the western, and on the southern edge is some slaggy stuff, extending on that side almost down to the sea, which forms a sort of cake looking like an accumulation of 'lava slobber.' The sides of the crater are very steep, the bottom is shaped like a saucer."[1] The height

[1] From the Author's diary, January 3, 1876. Sir C. Lyell (*Principles of Geology*, chap. xxiv.) quotes two separate contemporary descriptions of the event, from which the above account is compiled.

of Monte Nuovo is about 440 feet, and the bottom of the crater is only 19 feet above sea-level. The form of other craters in the Phlegræan Fields is generally different from that just described, for they are broad in proportion to their depth, and the cones, if indeed that name be appropriate, are comparatively low. No lava appears actually to have flowed from Monte Nuovo during this solitary eruption, although the frequent mention of "fire" and of a glow at night shows that some must have been exposed at the bottom of the crater. The cone, like many of minor size in other parts of the world, was built up by ejections of fragmental material, mainly scoria and volcanic mud.

Vesuvius has exhibited alternating eras of quiescence, and of more or less paroxysmal activity. Monte Nuovo, up to the present time, is the result of a solitary and brief outburst; but a few volcanoes exist which continue for ages in a condition of subdued but almost uniform action. Of the last type, Stromboli, one of the Lipari Islands,[1] is a good example. The whole group is volcanic, and its members are probably ranged along a fissure, which is forked like the letter Y. Two of the craters are active, some extinct. Vulcano, one of the former, exhibits paroxysmal phases, but Stromboli, the largest of the group, is always on "the boil." It is a conical hill, somewhat modified in outline by the action of storm

[1] For full descriptions see J. W. Judd, *Geol. Mag.*, 1875, p. 1 *et seq.*, and for later history, L. W. Fulcher, *Id.*, 1890, p. 347.

and wave, which is wholly composed of volcanic material, and rises to an elevation of rather more than 3000 feet above the sea.[1] The crater in action is not, however, at the summit, but about a thousand feet lower down, on the north-west slope. During quite 2000 years[2] Stromboli has been at work, puffing out steam, which at night glows intermittently with a ruddy light, resembling, except for its irregularity in occasion and intensity, the flashing light of a lighthouse.[3] The aspect of the interior of the crater is thus described by the late Mr. Poulett Scrope, who visited Stromboli in 1819: "The actual aperture of the volcano at the bottom of its semicircular crater is completely commanded by a neighbouring point of rock, of rather perilous access, from whence the surface of a body of melted lava, at a brilliant white heat, may be seen alternately rising and falling within the chasm which forms the vent of the volcano. At its maximum of elevation one or more immense bubbles seem to form on the surface of the lava, and, rapidly swelling, explode with a loud detonation. This explosion drives upwards a shower of liquid lava, that, cooling rapidly in the air, falls in the form of scoriæ. The surface of the lava is in turn depressed and sinks about twenty feet, but is propelled again upwards in a few moments by the rise

[1] The mountain can be traced below the surface of the water to a depth of nearly 600 fathoms, so that the total height of the volcano is considerably more than 6000 feet.

[2] Daubeny, *A Description of Active and Extinct Volcanoes*, chap. xiv.

[3] Judd, *Volcanoes* (International Scientific Series), chap. ii.

of fresh bubbles, or volumes of elastic fluids, which escape in a similar manner. . . . There evidently exists within and below the cone of Stromboli a mass of lava of unknown dimensions, permanently liquid, at an intense temperature, and continually traversed by successive volumes of aeriform fluids, which escape from its surface, thus presenting exactly all the characters of a liquid in constant ebullition."[1] Professor Judd[2] gives a generally similar but still more minute description from his own observations in 1874, and describes an outburst, slightly more energetic than usual, which he witnessed and sketched on the morning of April 24th. "Before it numerous light curling wreaths of vapour were seen ascending from fissures on the sides and bottom of the crater. Suddenly, and without the slightest warning, a sound was heard like that produced when a locomotive blows off its steam at a railway station; a great volume of watery vapour was at the same time thrown violently into the atmosphere, and with it there were hurled upward a number of dark fragments, which rose to a height of 400 or 500 feet above the crater, describing curves in their course." Most of them tumbled back into the crater, but some fell outside. Of the latter, certain "were still hot and glowing, and in a semi-molten condition, so that they readily received the impression of a coin thrust into them."

We pass on to another episode in the history of a volcano, and this time to that region of eruptions

[1] *Considerations on Volcanoes*, p. 17 (Ed. 1825). [2] *Volcanoes*, chap. ii.

and earthquakes—the islands of Japan. In the central part of Honshu, some 180 miles from Yokohama, Bandai-san or Kobandai-san formed the terminal peak of a block of mountains rising to a height of over 5000 feet above the sea. No eruption had occurred, so far as known, for at least a thousand years, though the presence of hot springs indicated that the furnace had not yet become cold. The morning of July 15, 1888, was perfectly fine, but rumbling noises were heard soon after seven o'clock, which the villagers on the lower slopes of the mountain attributed to distant thunder. A rather severe shock of earthquake was felt about half-past seven, which lasted for about twenty seconds. Shortly afterwards the ground was again most violently shaken, and then, while it was still heaving, the eruption began.[1] A dense column of dust and steam was shot up into the air with a tremendous report. Explosions followed one another to the number of fifteen or twenty, the steam on each occasion being discharged full 4000 feet vertically into the air. "The last explosion, however, is said to have projected its discharge almost horizontally towards the valley on the north, and, considering the topography of the mountain and the form of the crater, it is probable that previous discharges were also more or less inclined to the horizontal[2] in

[1] The time is given as 7.45 A.M.

[2] This account is abbreviated from an official report, extracts from which are published in an illustrated pamphlet by Sir J. B. Stone, M.P., entitled, *A Visit to Bandai-san.*

a northerly direction. The main eruptions lasted for a minute or more, and were accompanied by thundering sounds, which, though rapidly lessening in intensity, continued for nearly two hours. Meanwhile, the dust and steam rapidly ascended, and spread out into a great cloud like an open umbrella. At the immediate foot of the mountain there was a rain of hot scalding ashes, accompanied by pitchy darkness. A little later darkness was still great, a smart shower of rain fell, which was quite warm, and lasted for about five minutes. The most striking feature in the whole of this eruption was the deluge of rocks and earth. The destructive agency was merely the sudden expansion of imprisoned steam, unaccompanied by lava-flows or pumice ejections. When the explosion took place a considerable amount of rocks and earth was projected into the air, and a part diffused in the form of dust; but by far the greater part of Kobandai was first split into mighty fragments, which were thrown down much after the manner of a landslip. Descending the mountain-side with ever-accelerating velocity, the components of these avalanches were dashed against obstacles in their way and against each other, and were thus rapidly reduced to confused masses of earth and rocks. The loose and friable *débris* thus produced ultimately lost its adhesive power, and might be compared with a little exaggeration to sand." At first the stuff behaved like a fluid, but, gradually, on nearing the plain below, it lost speed, and finally came

rather suddenly to rest. Besides this, a sticky, scalding mud-rain fell, a mixture of condensing steam and ejected dust, which produced terrible burns and killed many persons. The fall of dust did not entirely cease till about eight hours after the eruption. At Miharu, a town twenty-four miles east of Kobandai-san, it began at 9 A.M. and lasted for five hours. Four hamlets were completely buried beneath the descending torrents of mud. Altogether, 461 persons perished, besides much cattle. Sometimes the people were buried under the ruins of their houses, but more often they were caught by the swift mud torrent while endeavouring to escape. The scene from the lip of the huge hollow formed by these explosions is thus described three years afterwards by Sir J. B. Stone[1]:—"We stood upon the brink of the precipice which formed the wall of the great inner rent, at the bottom of which lay the floor of the crater, and from which standpoint the most comprehensive view of the erupted area could be best seen. The comparatively level floor, some thousand feet below where we stood, was strewed over with boulders and rocky *débris*, and furrowed with the swill of watercourses. Upon our right were sloping cliffs, through which volumes of steam issued with a bellowing noise unearthly and terrible. On the far side of the crater, distant more than a mile, we could discern[2] stupendous walls, which had been cleft from the sides of Great Bandai-san. These cliffs,

[1] *Ut supra*, p. 22.

[2] The day was wild and rainy.

following the line of fracture, are perhaps the most wonderful objects in the whole panorama. For some miles they display a clean fracture, presenting to view such a unique and superb geological section as to excite the greatest admiration. On our left was the lower rent or lip fracture, through which, or rather over which, the detached mountain was hurled. The inside cliffs here are perhaps two hundred feet deep; and a survey of the crater and the form and general appearance of the enclosing walls convey an excellent idea of the operating force which upheaved the conical top of the mountain bodily, in one mass, as it were, and cast it overboard." It seems evident that the summit of Kobandai-san was obliquely truncated in the course of little more than a minute by a rapid succession of tremendous explosions,[1] which hurled into the air a mass of *débris* estimated as amounting to more than fifteen hundred million cubic yards.

A catastrophe very similar to that which has just been related appears to have occurred, in 1822, on Galoongoon, Java, a volcanic mountain with a crater on the summit, which, however, had been inactive as far back as tradition told. Here, also, terrific explosions scattered enormous quantities of mud and lapilli over the neighbouring region, the *débris* being carried in some cases over a distance of forty miles. If we rightly understand the story,[2] which, however, is not always very clear, two outbreaks occurred,

[1] The convulsion, Sir J. B. Stone says, was distinctly explosive, and not strictly speaking eruptive, for no new lava or pumice was visible.

[2] See Lyell, *Principles of Geology*, chap. xxvii.

one in July and another in October, and in the second of these a huge cratered gulf was formed in the side of the mountain. The loss of life here was much more heavy than it was in Japan. Papandayang, another volcano in the same island, had already suffered a similar catastrophe. During an eruption in 1772, the whole of the upper part of the mountain was blown away, and the summit was reduced in height by not less than four thousand feet.[1]

We may refer to one more instance of intense paroxysmal action before passing on to some other features of an eruption. This was at the volcano of Krakatoa; its history, owing to the recency of the occurrence and other circumstances, has been much more fully recorded than has been the case with most of those already mentioned. Krakatoa is the largest of a group of islands, all except three very unimportant, which lie in the Strait of Sunda, between Sumatra and Java. These islands, in the opinion of experts, were nothing more than the relics of a huge cone, about eight miles in diameter at sea-level, which had been shattered at a remote and unknown epoch by a catastrophe such as has been described above, only on a yet grander scale. The principal fragment had been augmented by subsequent eruptions, so that it formed a hilly island rather more than five miles in length and three in breadth at the widest part, the highest cone in which, called Rakata, rose to a height of 2623 feet above the sea.

[1] *Ut supra*, chap. xxx.

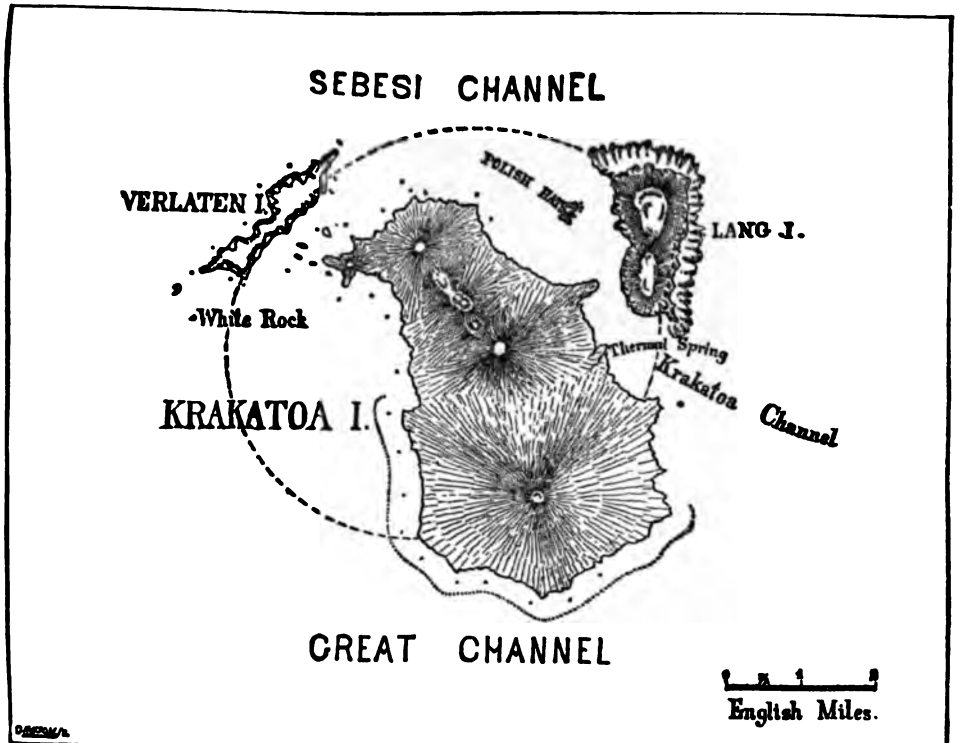


FIG. 4. MAP OF KRAKATOA PRIOR TO 1883.
The dotted line indicates the general outline of the original cone.

An eruption had occurred in 1680, but after that the volcano had been at rest for exactly two centuries. Then the region began to be shaken by frequent earthquakes. It was not, however, till 1883, that the eruptive period actually began. Then, on the morning of May 20th, booming sounds like distant artillery were heard at Batavia and Buitenzorg, towns the nearer of which is almost a hundred miles away. Next morning the captain of a passing vessel saw that an eruption had begun, for clouds of steam, dust, and pumice were being ejected to a height, it was estimated, of seven miles.[1] The eruption continued, sometimes slackening a little, for about fourteen weeks, and the place was visited by many parties from Batavia. Then came the day of the great catastrophe. The precise details will never be known, because the island was, fortunately, uninhabited. Little could be discerned from passing ships, and the peril was so great that the sailors had enough to think of in endeavouring to escape. This, however, is the sum of what was gathered from the disjointed reports. Soon after midday on August 26th the island was lost to sight under a cloud of black vapour, which rose above it, as was estimated, to a height of no less than seventeen miles[2]; loud explosions were heard; presently a rain of pumice

[1] Some of the finest dust drifted through the air to a distance of three hundred miles before it fell.

[2] Flashes of lightning were, as usual, frequent; even forty miles away corposants appeared on the rigging of a vessel, showing the peculiar electrical condition of the atmosphere.

began to fall. "Louder and louder became the explosions, blacker and blacker the cloud, yet more widespread the darkness, the storm, and the waves, till the paroxysms culminated on August 27th, when four explosions of fearful intensity shook earth and sea and air, the third being far the most violent, and productive of the most widespread results."[1] After these the eruption became less violent, and by the 29th was practically at an end. When next the island was visited an astounding change was seen to have been wrought. About two thirds of it, including all the lower part, together with the northern half of Rakata, were blown completely away. The remaining portion of its cone formed a huge precipice over a thousand feet high, facing towards the north. Where land had been there was now sea. This in some places was more than a hundred and sixty fathoms deep,

FIG. 5. SECTION OF KRAKATOA.
The dotted line giving the outline prior to the eruption of 1883, the dark line the one subsequent to it. The horizontal line marks the sea-level.

[1] *Story of our Planet*, Part iii., chap. ii. The full particulars are given in the Report of the Krakatoa Committee (Royal Society), 1888. The explosions occurred, as nearly as could be ascertained, at 5.30, 6.44, 10.02, and 10.52 A.M., Krakatoa time.

but by way of compensation the island in some places had been enlarged by the ejected materials. Other members of the group had been similarly changed, some being destroyed, some augmented by fallen *débris*. Enormous quantities of pumice, apparently formed during the eruption, had been hurled into the air. Much of this was so vesicular that it floated in the water, accumulating here and there in great banks, which covered the sea for miles, rising sometimes to a height of four or five feet above it. But in addition to this, immense volumes of dust had been discharged into the air, producing an awful darkness.

At Batavia, a hundred miles away, the effect was very similar to one of the blackest of London fogs. This began about seven in the morning of the 27th, and by eleven o'clock the town was in complete darkness, while a heavy rain, mingled with dust, was falling. That lasted about two hours, and then the air gradually cleared and the light returned. At Buitenzorg, which is at a still greater distance, darkness and a similar rain came on, though for a shorter time. The dust-cloud travelled far, for it was estimated that its materials had been shot up to a height of about twenty-five miles above the surface of the earth; the finer particles are thought to have floated through the air till they made more than the circuit of the globe.[1] Huge waves, caused either by the

[1] The extraordinary afterglows of November and December, 1883, were attributed to the minute powder which was still floating in the higher part of the atmosphere.

earthquakes or the explosions, devastated the low-lying shores of Java, Sumatra, and other islands, and the oceanic disturbance, though it soon ceased to be serious, was traced as far as Cape Horn, possibly even to the English Channel. Places more than two thousand miles away heard the reports of the explosions, and the waves of atmospheric disturbance were proved to have made more than one circuit of the globe.[1]

The amount of lava ejected by a volcano is variable —very often none is emitted on occasions when the explosive action has been most intense. But we shall see that while some volcanoes discharge only fragmental material, scoria, dust, and broken rock of different kinds, so others might be more correctly designated fountains of lava. The volcanoes of the Sandwich Islands, for instance, are very largely built up of great sheets of lava, and Kilauea, one of the most remarkable, though not one of the most lofty, might be described as simply a gigantic cauldron of molten material. Here anything approaching true explosive action is very rare, though an eruption of the ordinary type did occur about the year 1789.[2] The crater is an irregularly oval pit, fully two and a

[1] One fact in connection with this eruption is significant. The older lavas of Krakatoa contain but little water. In the obsidian ejected during the eruption of 1883 the amount was so large that a piece under the blow-pipe bubbled up into stony foam, just like the pumice mentioned above, which it was estimated had been dilated to about five and a half times its original bulk. (Prof. Judd, in Krakatoa Report, p. 37.)

[2] At this date there were no white people in the island, and the native traditions, though precise as to the fact, are not very clear as to the date.

half miles long, and about one and three quarters in greatest width, within which, about six hundred and fifty feet below the brim, is a kind of floor or terrace. Inside this—like a huge pot—is the more active part of the volcano.[1] At times the latter crusts over, leaving only here and there lakes of the molten basalt. It was in this condition in 1840, when examined by the late Professor Dana, who gives the following account of its appearance[2]: "The interior of the crater, an area two and a half miles long, covering nearly four square miles, was a desolate scene of bare rock. Instead of a sea of molten lava 'rolling to and fro its fiery surge and flaming billows,' the only signs of action were in three spots of a blood-red colour, which were in feeble but constant agitation, like that of a cauldron in ebullition. Fiery jets were playing over the surface of the three lakes, but it was merely quiet boiling, for not a whisper was heard from the depths. And in harmony with the stillness of the scene white vapours rose in fleecy wreaths from the pools and numerous fissures, and collected over the large lava-lake into a broad canopy of clouds. . . . When on the verge of the lower pit a half-smothered gurgling sound was all that could be heard. Occasionally a report like musketry came from the depths; then all was still again, except the stifled mutterings of the boiling lakes. In a night scene from the summit, the large cauldron, in place of

[1] This, in 1841, was about 350 below the end of the floor. The chief centre of activity is at the south-west end, which bears the name of Halema'uma'u.

[2] *Characteristics of Volcanoes*, p. 68.

a bloody glare, now glowed with intense brilliancy, and the surface sparkled all over with shifting points of dazzling light like a 'network of lightning,' occasioned by the jets in constant play; at the start of each the white light of the depths breaking through to the surface. A row of small basins on the south-east side of the lake were also jetting out their glowing lavas. The two smaller lakes tossed up their molten rock much like the larger, and occasionally there were sudden bursts to a height of forty or fifty feet. The broad canopy of clouds above the pit, and the amphitheatre of rocks around the lower depths, were brightly illumined from the boiling lavas, while a lurid red tinged the more distant walls, and threw into ranging depths of blackness the many cavernous recesses. The next night streams of lava boiled over from the lake, and formed several glowing lines diverging over the bottom of the crater."

At that time, as already mentioned, this lower part was nearly three hundred and fifty feet beneath the inner terrace or ledge, for the volcano had been partly exhausted by a recent eruption, but occasionally the glowing flood rises to a much greater height, and the area of its surface is far more extensive. Now and again an actual overflow occurs from Kilauea, but commonly the great lava column is either at rest, or rises and falls slowly like that of some gigantic mercurial barometer. To quote again from Professor Dana's volume,[1] there were three great eruptions

[1] *Ut supra*, p. 74.

between the early part of 1823 and the summer of 1840, with intervals of from eight to nine years. "The method of change was, in a general way, alike for each interval, from the emptied state of the pit to that of high-flood level preparatory to discharge, and alike in the down-plunge of the floor consequent on the discharge. Further, the various accounts agree in referring the filling of the pit to outflows of lavas from lava-lakes, cones, and fissures over the bottom of the crater, and in mentioning no facts that point to other concurring means." Since then the volcano has been more narrowly watched, and several careful descriptions have been published, not only by Professor Dana, who revisited the Hawaiian Islands in 1887, but also by Captain Dutton[1] and other observers. No very important additional feature has been noted during this time, and the eruption of 1840 has evidently been in several respects the most interesting on record, though this, unfortunately, was not watched by any of the foreign residents, for the Rev. Mr. Coan, to whom we are indebted for numerous careful observations on Kilauea, happened to be absent from Hilo just at that time. But he was informed by many natives[2] that for a week previous to the eruption the interior of Kilauea was "one great sea of liquid fire," and that the ground around so trembled from the action below that the islanders avoided the path along the verge of the crater. In

[1] *Fourth Annual Report of U. S. Geological Survey*, p. 81.
[2] Dana, *ut supra*, p. 62.

this the lava evidently had risen high; according to some accounts it threatened to overflow. Then it made its appearance at the bottom of a small pit-crater, five miles south-east of Kilauea. In that, according to the natives, it rose to a height of three hundred feet, a statement which was confirmed by the scoria left within. "Next followed small ejections on the surface near by, where other fissures had opened, and, simultaneously, the lava of the crater sank and disappeared." Other small openings and ejections occurred rather lower down the eastern slopes of the mountain, and finally, on June 1st, at a distance of 27 miles from Kilauea, the lava broke out at a height of 1244 feet above tide-level in a great flow, which, two days later, reached the sea, full eleven miles away. This stream, however, according to Dana and to Wilkes, who both visited the district at the end of the year, was not an overflow from a single opening, but the lava issued from several fissures along its whole course, and it continued to run for three weeks. "There was no earthquake, no shaking of the mountain. At Hilo not the faintest rumbling was heard or felt, and only slight quiverings to the north. A light was seen in the distance, but there were no inhabitants in the region, and it was supposed to be a jungle on fire." Occasionally the lava stream had undermined and borne along on its surface masses of rock and vegetation. It had swept away forests in its course, but sometimes it had parted and enclosed timber-covered islets. The trees on

these often still lived, only those being killed over a zone at the edge a few yards in width. The lava sometimes flowed round the stumps of trees, and these, as they were consumed, left deep, cylindrical holes, either empty or filled with charcoal. The lava had evidently been in an extremely liquid condition, for it was even found hanging in stalactites to the branches of trees, about which, in some cases, it was actually clasped. Yet so rapid had been the cooling of the surface that the bark was barely scorched. Lava, particularly such as that of Kilauea (basalt), is a very bad conductor of heat. Here and there on the surface of the flow were miniature cones a few yards in height, out of which the lavas had spouted for a while after the stream had flowed on. Many fissures and caverns were sending up hot vapours, and in some the rocks were yet[1] glowing within a few feet of the surface. When the great flow reached the sea it plunged into it with loud detonations, extending the coast-line outward for nearly a quarter of a mile, and so heating the waters that for twenty miles the shores were strewn with dead fish. "The burning lava on meeting the waters was shivered like melted glass into millions of particles, which were thrown up in clouds that darkened the sky and fell like a storm of hail over the surrounding country. The light 'was visible for over a hundred miles at sea, and at the distance of forty miles fine print could be read at midnight.'"

[1] In the month of November, 1840.

Thus the cycle of movement in Kilauea, since 1823, has been as follows: (1) a rising in level of the liquid lavas, and of the bottom of the crater; (2) a discharge of the accumulated lavas down to some level in the conduit determined by the outbreak; (3) a down-plunge of more or less of the floor of the region undermined by the discharge. The outbreak just described indicates that the lava found a comparatively easy passage from the principal supply basin of Kilauea to the point where it began to flow upon the surface, and apparently all along the line of its course to the sea. The mountain, therefore, may be cleft by some ancient fissure, which was but imperfectly healed, and was again rent open by the pressure of the lava enough to allow of that at first reaching the surface here and there, and at last, in the lower part of the mountain, escaping freely along a line perhaps over ten miles in length.

Before quitting Kilauea and its neighbourhood we may call attention to certain other facts, since they will be found to throw some light on the history of volcanoes in general. Of these Professor Dana has given a summary, and has also indicated their theoretical bearing. The slopes around Kilauea are low, and the same remark holds good of the great mountain,—Mauna Loa,—on the flank of which its crater has opened out, as well as of the other Hawaiian volcanoes. Their angle usually does not exceed ten degrees, and it is often less, though, occasionally, a lava stream may descend a steep slope or even take a pre-

cipitate plunge without interruption of continuity, so that the mass resembles a frozen cascade, such as may be seen, however different in colour and translucency, in any mountain region during the winter season. We cannot examine an outline drawing of one of the greater volcanic mountains, such as Mauna Loa or Mauna Kea, without perceiving how remarkably its low, mound-like curve differs from that of the truncated and rather steep cone which is regarded by most persons as typical of a volcano.[1] This somewhat exceptional character is due to the nature of the materials. They consist in the Sandwich Islands of a heavy but rather fusible rock called basalt, which, for reasons to be noticed in a later part of this volume, is usually ejected at a temperature considerably above its melting-point. Thus the lava is more mobile, and yet more dense, than any of the varieties called trachyte, using the term in its more general sense (including, for instance, that ejected from Cotopaxi), and acquires a greater velocity on slopes and flows more easily, for it is less liable to be impeded by obstructions. On this account it has a lower minimum angle of flow, and its lava cones have a more gentle slope. The latter statement indicates another characteristic of these volcanoes. An ordinary cone—with an angle of slope not seldom rather

[1] This, of course, is very commonly exaggerated by the artist, as may be seen in the caricature which, since the days of Humboldt, has done duty (till Mr. Whymper showed us its true form) for Cotopaxi. As all who have sketched in mountainous regions know, it is hardly possible to avoid drawing slopes steeper than they are in nature.

greater than twenty degrees—proves on examination to consist largely of fragmental materials, scoria and ash of various sizes, ranging commonly from fine dust to blocks a foot or so in diameter, but occasionally considerably more. Here and there a driblet of lava is incorporated with these materials, and sometimes a larger sheet, which, however, is rarely thick, or a dyke, where the same material in its upward and outward course has filled up a fissure in the wall of the crater or the flank of the cone. But notwithstanding these, the mountain, so far as it can be examined, is composed of fragmental materials, the solid lava forming only a comparatively small proportion of the whole mass. But, in the Sandwich Islands, according to Professor Dana, dust and scoria are rarely ejected from the craters. In such examination as he was able to make of the walls of Kilauea, Haleakala, and the precipices and bluffs of Oahu, he did not succeed in finding deposits of this kind intercalated among the lavas which entered into the composition of the body of the mountain, though they are a common feature where lateral cones have been thrown up.

It would therefore appear that where orifices are large the lava wells out quietly and builds up the great mountain masses layer by layer, dust and scoria being only produced at subsidiary "blow-holes," where, from some cause or another, a slight concentration of steam has produced a limited amount of paroxysmal action. This steady flow with mere local spurting often occurs, as will be seen hereafter,

whenever large masses of lava are welling up, either through one great orifice or through many fissures. Kilauea also, as Professor Dana points out, occasionally affords an indirect but convincing proof of the great area of the lava column, which sometimes rises and falls in its crater almost like the mercury in a barometer. In 1823, for instance, the floor of the crater actually dropped abruptly to a depth of some hundreds of feet, leaving only a narrow shelf along the sides. This indicates that the area of the lava column beneath the floor was about equal to that of the Kilauea pit, the circuit of which is seven and a half miles.[1] We may also infer that immediately before the discharge, wherever a lava lake was visible, the liquid top of the column had risen up to the floor of the crater, and elsewhere was not far below it. Similar inferences may be drawn from the eruptions of 1832 and 1840. When the floor of the pit fell at the discharge during the second of these, it "was not thrown into hills and ridges, as it might have been had it dropped down its four hundred feet to solid rock in consequence of a lateral discharge of the lavas beneath. On the contrary, it kept its flat surface, thus showing that it probably followed down a liquid mass, that of the subsiding column of lava." Professor Dana goes even further and adds, in regard to the area of the lava column, some reasons in favour of its having extended, at any rate in one direction, even beyond the wall of the crater, though

[1] *Loc. cit.*, p. 151.

in these parts the liquid mass probably does not come quite so near to the surface, or, in other words, its top is not level, but curves downwards from the crater itself.

When lava is ejected in large quantities it is more usually discharged from a fissure than as an overflow from the crater. Sometimes, as has occurred on Vesuvius, the rent is made in the actual cone, but even here it may open at a lower level.[1] For instance, a lava stream which was discharged in 1861 evidently flowed from a fissure. This, at the upper end, can be seen running up the face of a cliff nearly fifty feet high, formed of the yellowish-grey ash of the mountain.[2] At its foot the fissure widens, and one can just discern the rough top of the lava. From this point a line of cones, about nine in number, runs down the hillside, marking the blow-holes of the "fiery serpent" as it crept on in its underground course, until at last it emerged and streamed down the mountain-side.

Other instances may be found on Vesuvius itself, but all these are comparatively small. We will, however, in conclusion, cite one, from another locality, where the mass of lava discharged not only, in all probability, much exceeded even that from Kilauea, but was also accompanied by the usual phenomena of

[1] In some cases also the pressure of the lava, when it has welled up in the cup of the crater, effects a breach in the enclosing mound, and the molten mass pours out through this as from a flood-gate.

[2] This belonged, as it seemed to me, to the cone which was in existence prior to A.D. 79.

a volcanic eruption. This was the terrible outburst from Skaptár Jökull in Iceland.[1] It began in the month of June, 1783, and was the first from this volcano which is recorded in the annals of the island. There was the usual prelude. The inhabitants of a neighbouring district were alarmed by repeated earthquake shocks, which began on the first day of the month and increased in violence until the eighth. Then the eruption commenced. Vast clouds of dense smoke were discharged from a place which was hidden from their view by intervening lower hills, dust and pumice began to fall, loud reports were heard, flashes of lightning and peals of thunder were almost incessant. On the tenth, the glowing lava became visible, flowing along a valley in a south-westerly direction till it reached the river Skaptâ, the water of which was ultimately all but dried up. In fact, the lava torrent completely filled the glen, which in places is from 400 to 600 feet deep. Here, however, it is narrow, being only 200 feet wide, and the lava overflowed on to the fields on either side. Where the glen opened out the lava continued its course, overwhelming fields and woods and farms. On June 18th it was reinforced by a fresh discharge from the mountain. This, after a time, parted into two branches, and destroyed many places which had escaped from the former invasion. But even that was not the end of the calamity, for, from June 22d to

[1] An account from materials collected during his stay in Iceland in 1814 and 1815 is given by E. Henderson in his well-known *Iceland*, vol. i., chap. vii.

July 13th, fresh eruptions occurred, and molten lava again streamed along the old tracks to widen the area of ruin.

Still later in the same summer a region to the east of the former one was invaded by a fresh outbreak of lava. Parallel with the Skaptâ valley, some miles away, is another river, the Hverfisfliot. The inhabitants of this valley, up to August, had suffered only from the fall of ashes and the effects of acid vapours which had destroyed the vegetation, but, on the third day of that month, the water of the river began to steam, and gradually dried up, for here also the channel was being occupied by molten lava. As in the former case, the valley was filled up, and by the ninth of the month the lava stream, reinforced by fresh ejections, had reached, and begun to overflow, the open and level country. The advance of the main masses was arrested before the end of August, but discharges still continued in the rear for some months. According to Henderson, the length of the stream which descended the Skaptâ valley is about fifty miles, and its greatest breadth in the lowlands is between twelve and fifteen miles; the other one is about forty miles long, and seven at the utmost breadth. The thickness of the mass is not generally more than 100 feet, but sometimes in the narrow part of the Skaptâ glen it reaches 600 feet. Different estimates have been made of the total quantity. Some have vaguely compared it to the volume of Mont Blanc. Helland reckons it as 25 cubic kilo-

metres,[1] and Thoroddsen puts it much lower, only 12⅓ cubic kilometres. But, in addition to this, enormous quantities of dust and ashes were discharged, heavy showers falling over no small part of Iceland,[2] and occurring sometimes even in the Faroes.

The source of the lava was visited by Dr. Tempest Anderson in July, 1890. Passing up the channel of the Skaptâ, now filled brimful of lava, so that the river runs upon its surface, he made his way to the place in the heart of the mountains. "Here," he writes,[3] "a truly marvellous spectacle presented itself; a vast fissure had opened out, many miles long, and varying from nothing at the end we saw first to perhaps ten feet at its widest part. Its direction was roughly S.W. to N.E. At the lower narrow end were first a few baby craters, a few feet high; then larger ones, mostly breached at one side where the chief flow of lava had taken place, and where the enormous masses of lava had solidified just as they came out in billows of fire a century ago. Further on, and higher up the fissure, we came to larger craters, rising to the size of respectable hills, perhaps 200 or 500 feet above the lava field. These are perfect on all sides, rounded or oval, and the great fissure can still be seen of a width of perhaps six to ten

[1] About 5⅛ cubic miles, or a slab about 100 yards thick and 82 square miles in area.

[2] The sufferings of the people were frightful. Though few were killed in the eruption, some hundreds were utterly ruined; and famine and pestilence followed. According to Henderson, during the next two years no fewer than 9336 human beings, 28,000 horses, 11,461 head of cattle, and 190,488 sheep perished.

[3] *Alpine Journal*, vol. xviii., p. 220.

feet running along the bottom of several. Traces of it are visible going under the great heaps of scoriæ, which separate adjacent craters and form their walls at these parts. The outer slopes of the cones are gentle, the inner walls of their craters nearly precipitous; this conformation being apparently due to the scoriæ having been ejected in a pasty condition, so that they stuck where they fell; and thus, while those which fell directly into the fissure were blown out again, those which fell out of the direct line attached themselves, and did not roll back to fill up the rent, as we so often see in ash-cones."[1]

Before quitting the subject of active volcanoes on land we may refer to one or two other instances, illustrative of more exceptional types of eruptive action. Two of these are furnished by Cotopaxi, in the Ecuadorian Andes. It is remarkable, not only for the symmetry of its form, but also from the fact that it is one of the highest of those which are still in action, for it reaches about 19,500 feet above sea-level,[2] and has had no period of absolute repose since the time when it became known to history. Mr. E. Whymper, who remained upon the summit for twenty-six hours, has given an excellent description of the ordinary demeanour of the volcano. The

[1] I have met with similar evidence, showing that fragments are sometimes in a pasty condition when they fall. In quarries near Mayen in the Eifel I found it almost impossible to fix the exact line at which the scoriaceous top of the lava stream ended, and the layer of actual scoria above it began.

[2] Reiss and Stübel (1872–73), by triangulation, found it 19,498 feet; Whymper (1880) made it, by barometer, 19,613 feet.

crater, at the time of his visit,[1] was about 2300 feet in diameter from north to south, about 1650 feet from east to west, and about 1200 feet in depth. The sides were generally steep, in places actually precipitous. "Cavernous recesses belched forth smoke, the sides of cracks and chasms no more than half-way down shone with ruddy light, and so it continued on all sides, right down to the bottom; precipice alternating with slope, and the fiery fissures becoming more numerous as the bottom was approached." Here was "a rudely circular spot, the pipe of the volcano, its channel of communication with lower regions, filled with incandescent, if not molten lava, glowing and burning, with flames travelling to and fro over its surface and scintillations scattering as from a wood fire; lighted by tongues of flickering flame which issued from the cracks in the surrounding slopes. At intervals of about half an hour the volcano regularly blew off steam. It rose in jets with great violence from the bottom of the crater and boiled over the lip, continually enveloping us. The noise on these occasions resembled that which we hear when a large ocean steamer is blowing off steam. It appeared to be pure, and we saw nothing thrown out, yet in the morning the tent was almost black with matter which had been ejected."[2] Mr. Whymper, however, thinks that this "puffing" is not the normal habit of the volcano, for

[1] *Travels in the Great Andes of Ecuador*, chap. vii.

[2] See page 67.

it hardly could have been going on at times when he had opportunities of watching the summit of the mountain, and had seen the clouds of steam quietly simmering from the crater, and it is not mentioned by his predecessors. He had, however, already observed the same phenomenon even more markedly exhibited by Sangai, a volcano which he only saw at a distance. Here, though hardly any smoke was issuing from the crater, outrushes of steam took place at intervals of twenty to thirty minutes, which shot up with immense rapidity five or six thousand feet above the top of the mountain.[1] They then "spread out into mushroom-like clouds," which were drifted away by the wind.

But on a later occasion Cotopaxi afforded an instance of a remarkably sudden discharge of fine materials. It was when Mr. Whymper and his companions were ascending Chimborazo for the second time, in the early morning, soon after they had left their camp.[2] "The sky was bright, the air serene, and long before dawn, sixty miles away, we saw the cone of Cotopaxi clear-cut against a cloudless horizon, and remarked how tranquil the great volcano looked, and that not a sign of smoke was rising from its crater. Soon a cold wind sprang up. I lingered behind to beat my hands and feet, and while resting back against a rock, looking towards the north, saw the commencement of an eruption. At 5.40 two

[1] *Ut supra*, p. 74. The height of Sangai is given as 17,464 feet.
[2] *Ut supra*, p. 322. The date was July 3, 1880.

puffs of steam were emitted, and then there was a pause. At 5.45 a column of inky blackness began to issue, and went straight up into the air with such prodigious velocity that in less than a minute it had risen 20,000 feet above the rim of the crater." At that elevation it was caught by a powerful wind from the east and blown towards the Pacific. Mr. Whymper in the account of his ascent describes the path of the dark cloud, how it was afterwards caught by another air current and gradually borne towards Chimborazo. Till about ten o'clock they could see that the immense column continued to rise from Cotopaxi, but after that it was shut out by the approaching cloud of dust. At last, about midday, this passed over their heads at a height, as they estimated, of not less than 5000 feet above the summit,[1] and finally, about ten minutes after their arrival, the light dust began to fall on the hitherto pure snow.[2]

An earlier eruption of Cotopaxi in June, 1877, was exceptional in more than one respect. During the first half of the year the volcano had been rather unusually restless, discharging columns of steam and dust, which sometimes rose to a height of a thousand feet above the crater, and at night reflected the glow of incandescent material within. On June 25th a huge column of smoke was ejected, which was estim-

[1] The height of Chimborazo, according to the triangulation of the French academicians, is 20,592 feet; to that of Reiss and Stübel, 20,703 feet; while Mr. Whymper obtained by barometer 20,545 feet on one occasion and 20,475 feet on the other.

[2] For description of the materials see page 68.

ated to be as high as the mountain itself, and was accompanied by tremendous subterranean bellowings. Early next morning another great column spouted up, then, about ten o'clock, some people on the windward side of the cone saw "molten lava pouring through the gaps and notches in the lip of the crater, bubbling and smoking, so they described it, like the froth of a pot that suddenly boils over. The scene which then ensued upon the mountain was shut out from mortal eye, for in a few minutes the whole of it was enveloped in smoke and steam, and became invisible; but out of the darkness a moaning noise arose, which grew into a roar, and a deluge of water, blocks of ice, mud, and rock rushed down, sweeping away everything that lay in its course, and leaving a desert in its rear." This terrible flood streamed down the slopes of Cotopaxi and far away over the surrounding region, following the courses of the valley. Places a hundred and fifty miles away in a direct line felt its effect. Its rate is said to have been at first fifty miles an hour, and Mr. Whymper thinks this not impossible. He ascertains by calculation that the mean rate up to the above-named distance was seventeen miles an hour. In his opinion the lava fell again in the crater almost as quickly as it had risen, for the floods ceased in about an hour, and a large quantity of ice near the summit remained unmelted. But, as he points out, the overflow of the lava through the many depressions of the crater-rim must have produced tremendous explosions as it

streamed down the slopes of snow and ice,[1] and these must have sent the molten stuff flying through the air to fall in a hail of liquid fire.

The majority of active volcanoes are situated on the land, but a considerable number are submarine. Many indeed of the islands that stud the Pacific, and the more isolated of those in the Atlantic, are of volcanic origin; possibly also some which are now only recognised as coral atolls may really cover the denuded summits of old volcanoes. The Sandwich Islands, to which we have already referred, appear to have been built up of volcanic materials from great depths.[2] This island group, according to Professor Dana,[3] is "an example of a line of great volcanic mountains. Fifteen volcanoes of the first class have existed and have been in brilliant action all along the line." All but three in Hawaii, the largest island, are now extinct. This is made up of five volcanoes, two of which, Kea and Loa, tower to heights of 13,805 and 13,675 feet respectively. The depth of the surrounding ocean varies from 2000 to 3000 fathoms. If, then, its waters were to disappear we should see the composite volcanic mass of Hawaii rising in places 28,000 feet, and perhaps even more, from the undulating plain on which it had been built up.

Many other oceanic islands have had a similar

[1] Snow on Cotopaxi appears to be fairly continuous above a height of about 16,000 feet.

[2] Some littoral deposits, more or less of organic origin, must be excepted from this general statement.

[3] *Ut supra*, p. 25.

origin, and the submerged portions not infrequently are 12,000 feet or more in vertical height. What is their construction, what proportion the lava-flows bear to the fragmental materials, we can only conjecture; but the former not infrequently predominate, at any rate, in the part of the island that lies nearest to the present surface of the water.[1] We should expect that, in the case of a submarine eruption, since the molten material would be brought immediately into contact with water, violent explosions would result. These should be favourable to the production of fragmental materials, but the latter could not be dispersed to anything like so great a distance from the centre of eruption as they are when that is open to the sky. We should expect also that the resistance of the water would prevent the lava from flowing so far as it would have done on land, and might also in some cases cool its surface more rapidly, so that submarine flows ought to be more limited in area, but proportionately thicker than subaërial. Again, if the water is deep, that is to say, in the earlier stages of building up the cone, the mass of overlying fluid may produce somewhat the effect of a feather bed, and restrict the propagation of the more violent disturbances. Such explosions as those at Krakatoa, and the violent agitation or ebullition of the sea, of which we occasionally read, appear, so far as we can tell, to occur only when the summit of the volcano is

[1] This is especially true of the Hawaiian volcanoes.

approaching the surface. The examination of "dissected volcanoes," *i. e.*, those which became extinct in past geological ages, enables us, as we shall presently see, to form some conjectures as to the history of submarine eruptions; but so long as we confine ourselves to those still in activity we can only describe what happens when the volcano is passing, or has just passed, from the subaqueous to the subaërial condition. As an instance of this we can find none better than the classic one of Graham Island, which was born, and may be said to have died, during the present century.

Prior to 1831, the bed of the Mediterranean, at a spot about thirty miles S.W. of Sciacca in Sicily, and thirty-three miles N.E. of the island of Pantellaria, was full 100 fathoms deep. On June 18th, as an English ship was sailing over this place, earthquake shocks were felt, as though it had struck on a sand-bank. On July 10th, a column of water 800 yards in circumference was seen spouting up from the sea to a height of sixty feet, which was presently replaced by dense clouds of steam, which rose into the air to thirty times that elevation. By July 18th a small island had appeared, rising about a dozen feet above the water, and with a central crater, from which quantities of scoria, much of it light enough to float on the sea, and immense columns of vapour were being ejected. The eruptions continued to the end of the month, when the island had grown to three-quarters of a mile in circumference, and from

fifty to ninety feet in height. It continued to grow till early in the next month, when it is said to have reached its maximum size of three miles in circumference, and above 200 feet in height. After that no more solid matter seems to have been discharged, though the agitation of the sea and the ascent of a cloud of steam to the S.W. of the island during part of that month seem to indicate the opening of a parasitic vent. It did not, however, show itself above water, and the new island began to disappear rather rapidly before the waves. On September 3rd, when it was carefully examined, it had been reduced to three-fifths of a mile in circumference, and 107 feet in greatest height. By the end of October it was almost gone, and early in the following year it had quite disappeared. When a survey was made towards the end of the following year it had quite disappeared. When a survey was made towards the end of 1883 a dangerous reef was found, an oval in outline and about three-fifths of a mile in extent. It was formed of scoria and sand, and in the centre of it was a black rock, rather more than fifty yards long, which was at a depth of from nine to eleven feet. About 150 yards away from this, and to the south-west, was another reef at a slightly greater depth. The larger mass, as Sir C. Lyell observes,[1] probably marks the site of the main crater, the smaller one that of the secondary eruption.

[1] *Principles of Geology*, chap. xxvii., from which the particulars given above have been taken.

Another and more recent instance may be quoted of the building-up of a volcano from beneath the waves, although in this case on a spot marked by the remains of some prehistoric eruption.[1] In Behring Sea, prior to the middle of the last century, was an isolated rock, about forty miles west of Unalaska Island, in latitude 53° 58′ N., longitude 168° W. It is indicated on Russian charts, and it was seen by Captain Cook in 1778. But, in 1795, the natives on Unalaska Island observed that a fog, apparently persistent, overhung the site of this rock. At last one of them, more curious and courageous than the rest, went off to investigate the cause. He returned terror-stricken and reported that the sea all about the rock was boiling, and that the supposed fog was in reality the steam which rose from it. At the same time the craters on Unalaska and Unimak Islands (the whole region is volcanic) were active. The disturbance around the rock increased, and in the month of May of the same year a great mass of matter was ejected, which rose above the water and formed the present island, which was named by the natives Agáshagok, by the Russians, Ioanna Bogoslova, which is simplified in English mouths to Bogosloff. In 1872, and again in 1873, Mr. W. H. Dall examined the island from a short distance, but was prevented by the state of the weather from effecting a landing. The island then rose about 850 feet

[1] The following account is quoted with some condensation from the description given by Professor I. C. Russell in *Volcanoes of the United States*, p. 276.

above the sea, and formed a sharp, narrow, jagged crest, on which no sign of a crater could be seen. The coast, except at the southern end where the waves had formed a small spit of shingle, was generally precipitous. Another eruption broke out at Bogosloff in 1883, simultaneously with one at Mount St. Augustine in Cook's Inlet. Again the island was hidden beneath a pall of dusky steam, which ultimately drifted over Unalaska Island. It excluded the light of the sun, and from it dull grey volcanic dust fell in considerable abundance. When the air again became clear it was found that the geography of Bogosloff had been greatly altered. A new island had risen about half a mile north-west of the old one, on a spot where formerly the sea had been deep enough to be navigated in perfect safety. New Bogosloff, as this addition was called, was linked to the original island by a narrow isthmus, and was in a phase of slight eruption in 1884, when a landing was effected by officers of the U. S. Revenue vessel *Corwin*. They describe the connecting isthmus as a kind of sand-bar formed by the waves, which has possibly been brought above the line of the sea by a slight upward movement, for some of the earlier observers represented the two islands as actually disconnected. New Bogosloff, according to Lieutenant Cartwell, one of the landing party, forms a rather gently sloping cone with a crater at the summit, which at first rose to a height varying from 500 to 800 feet. Its slopes are covered with an incoherent dust of extreme fineness,

so that the ascent proved to be very laborious, especially on the upper part, where the climbers sank knee-deep and stirred up clouds of suffocating powder. Steam escaped from fissures on all sides of the cone, in some places intermittently, in others continuously, and these emissions were accompanied by deposits of sulphur. No lava or ashes were seen to be ejected from the crater, though at night bright reflections were visible from the glowing mass at the bottom. When the hill was first observed from a passing vessel great quantities of steam and ashes were being discharged from the summit and from numerous fissures in the sides and base, while at night bright reflections were visible from the highly heated interior.

In the intervals between the paroxysmal phases most volcanoes emit simply steam, and all in their decadence pass through a longer or shorter period when it alone is ejected. This is often termed the solfatara stage, from the crater of that name in the Phlegræan Field. Like most of those in this district the cone is low and the crater wide; the floor is a level, sometimes marshy, plain, surrounded by steep walls of ashy materials, perhaps a hundred feet in height. The last eruption was in 1189, when a stream of trachytic lava was discharged from the southern side of the crater. But now the sole sign of activity, except some boiling puddles in one part of the floor, is to be found at the foot of the crag on the side. Here, from a fissure in the enclosing

wall, something like the adit of a mine, a column of steam is ejected to a height of six or seven yards. This steam commonly is more than the vapour of water. Such acids as hydrochloric or sulphuric are often present[1]; that of the Solfatara, as we can see from the sulphur abundantly deposited round the aperture and the rotten condition of the adjacent rocks, is no exception to the rule. No doubt the materials in and about a vent must undergo considerable chemical changes when the volcano is passing through this stage in its history.

A yet further stage is when steam has ceased to rise, perhaps even hot springs to flow; but the volcano is not yet quite extinct. It may be said still to breathe, and its dying breath is foul. Occasionally a crater discharges only carbonic acid, as appears to be the case with the famous Guevo Upas, or Valley of Poison, in Java, the bed of which has become a pool of carbonic acid, where lie the bones of birds, beasts, and even men. To enter it is death, for the vapour does its work even more quickly and surely than water. Similar to this, though less directly connected with actual craters, are the famous Grotto del Cane, in the Phlegræan Fields, and that cellar-like recess under an old lava stream near Royat, in Auvergne. Springs, indeed, of carbonic acid gas are by no means uncommon in regions of extinct vol-

[1] The steam emitted from Vesuvius in January, 1876, was acid with these, particularly the former. Steel was rusted, and clothes were slightly altered in colour in the course of an hour or two.

canoes, such as the Eifel; and these, where local circumstances are favourable, form pools which become death-traps for the smaller animals.

The mud volcano may be regarded as a particular instance of the solfatara stage. Streams of mud, as we have shown was the case with Vesuvius in A.D. 79 and Cotopaxi in 1877, often come rushing down from an ordinary volcano during an eruption; but these are formed by a mixture of the ejected dust with the condensed steam after both have been discharged, the mixture taking place either in the atmosphere or at any rate shortly after the fall of both. There are, however, cases more properly deserving the name volcanic where a hot spring has liquefied the sedimentary material, not invariably eruptive in origin, through which it passes, and in its occasional slightly paroxysmal phases builds up a low cone, in the crater of which the mud boils like porridge in a pot. Such exist at Baku, on the Caspian, and on both sides of the strait connecting the Sea of Azof with the Euxine. One, the Gorela, near Kertch, rises to the unusual height of 246 feet; and from its crater, which is perfectly distinct, streams of mud have flowed, one of which was 2624 yards in length, with an estimated volume of about 850,000 cubic yards.[1]

Among the most generally noted are those of Krafla or Krabla, in the north of Iceland, which are described in graphic language by Mr. Baring-Gould. "Picture to yourself a plain of mud, the

[1] Reclus, *The Earth*, chap. lxix.

wash from the hills, bounded by a lava field. . . . From the plain vast clouds of steam rise into the air and roll in heavy whorls before the wind, while a low drumming sound proceeding from them tells of the fearful agencies at work. . . . Vents are in great numbers, but there are especially twelve large chaldrons in which the slime is boiling. In some the mud is thick as treacle, in others it is simply ink-black water. The thundering and throbbing of these boilers, the thud, thud of the hot waves chafing their barriers, the hissing and spluttering of the smaller fumaroles, and above all the scream of a steam-whistle at the edge of a blue-slime pond produce an effect truly horrible. In some of the chaldrons the mud is boiling furiously, sending sundry squirts into the air; in others, bells of black filth rise and explode into scalding sprinklings; in one, a foaming curd forms on the fluid, and the whole mass palpitates gently for a minute, then throbs violently, surges up the well, and bursts into a frenzied roaring pool of slush, squirting, reeling, whirling, in paroxysms against the crumbling sides, which melt like butter before its fury. One or two of the springs have heaped themselves up mounds around their orifices; others, however, gape in the surface without warning, and the steam is so dense and the sulphurous fumes so suffocating that one becomes bewildered, and can hardly pick one's way among them. . . . Around and among these chaldrons are small slobbering holes of all sizes, out of which

issue steam and slime; some widen in time into large boilers, and the old ones fall in. These changes are constantly occurring."[1]

A geyser exhibits the most paroxysmal stage of the hot spring, and one which, as we shall see hereafter, has a very important bearing on the whole question of volcanic action. It is, in fact, a water volcano, differing from a mud volcano only as the pure differs from the mixed fluid. A geyser consists of a pipe going down into the earth from a crater-like mouth at the top of a low cone, this being composed, not of ash or scoria, but of sinter; that is, of the silica which at one time was dissolved in the hot water, but has been precipitated by evaporation or cooling. Among the most noted geysers are those of Yellowstone Park in the United States, of Iceland, and of Rotomahana, in New Zealand. In the first-named district the geysers occur in a fairly level oval basin, about 2¼ miles long, which lies near the watershed of the continent, about 7300 feet above sea-level. They are forty-eight in number, each with its own characteristics, and springs are also numerous. Between the two, as Mr. W. H. Weed[2] pertinently remarks, it is not easy to draw a sharp line, "nor is it necessary, for there is every gradation, from a quiet pool with simple intermittent increase in temperature to the great fountains of boiling water, which provoke our wonder and our admiration." One of these has earned the name of

[1] Baring-Gould, *Iceland: Its Scenes and its Sagas*, chap. xii.

[2] *Ninth Annual Report U. S. Geological Survey*, p. 653.

FIG. 6. A GEYSER IN ERUPTION. "OLD FAITHFUL," YELLOWSTONE PARK.

Old Faithful, because it erupts at regular intervals of about sixty-three minutes. "It stands upon a low mound of sinter . . . . in the midst of which lies the vent of the geyser—a hole not more than a couple of feet or so in diameter—whence steam constantly issues. When we arrived[1] a considerable agitation was perceptible. The water was surging up and down a short distance below, and when we could not see it for the cloud of vapour its gurgling noise remained distinctly audible. We had not long to wait before the water began to be jerked out in occasional spurts. Then suddenly, with a tremendous roar, a column of mingled water and steam rushed up for 120 feet into the air, falling in a torrent over the mound, the surface of which now streamed with water, while its strange volcanic colours glowed vividly in the sunlight. A copious stream of still steaming water rushed off by the nearest channels to the river. The whole eruption did not last longer than about five minutes, after which the water sank in the funnel, and the same restless gurgitation was resumed."

The great geyser of Iceland is very far from imitating the punctuality of Old Faithful. This was Mr. J. F. Campbell's experience[2]: "Every few hours came the warning,—thud, thud, thud,—but nothing came of it. . . . All next morning the water rose and fell and sank and rose again, balancing. Tired of waiting, the party set off at last, and met

[1] Extract from a description by Sir A. Geikie, *Geological Sketches at Home and Abroad*, p. 261.

[2] *Frost and Fire*, vol. ii., p. 413.

a fresh party going to the place. They arrived in the nick of time, saw an eruption, and returned next day. In 1862 the disappointed returned. One party, who had very little time to spare, rode in hot haste to Haukadal, and saw many eruptions in a few hours. Those who followed more leisurely waited for three days, but this time they did see the show. It was a grand display, and well worth all the waiting. Instead of ending suddenly or gradually, the steam salute shot faster and faster, thuds followed each other rapidly, and the whole ground shook; then the sound of dashing water, the music of waves was added to the turmoil. A great dome rose in the middle of the pool and frequent waves dashed over the edge of the basin, while streams overflowed and drenched the whole mound. Great clouds of rolling steam burst out of the water domes and rose in the still air, swelling like white cumulus clouds against a hard blue sky. . . . At last, the whole pool, fifty and odd feet wide, rose up in a single dome of boiling water and burst, and then the column in the tube, seventy feet deep and twenty wide, was shot out of the bell-mouthed blunderbuss with a great burst of steam. The charge scattered . . . it rose about sixty feet, and most of it fell back and sank in with a rush; and so the glittering fountain rose thrice, like some mighty growth. After the last effort the pool was empty, and the pipe also for a depth of six feet."

But, as if to compensate for the irregularity of the great geyser, a smaller one, called Stokr (The Churn),

can be made to erupt by a very simple expedient. In shape it is a conical oval pit, less than six inches wide at the bottom, and about thirty-five feet deep. "The water is always surging, growling, and frothing about within six feet of the top. Steam rises through a hot column thirteen feet deep and never collapses, because there is less pressure to be overcome. This well boils, but does not simmer. By turning a barrowful of turf into the pit this kettle is made to boil over; steam is stopped, the water is stilled for some minutes, and the mud is greatly heated below. Then a dome grows and bursts, and wad and water and steam from the gun grow up like a giant sheaf of corn. . . . Up go the projectiles, and down they come in showers and streams, to rise again with furious bursts." [1]

The descriptions quoted in the preceding pages lead us to define a volcano in some such terms as these: "It is an orifice in the crust of the earth, commonly terminating in a bowl-like hollow called a crater, which forms the summit of a mountain or hill usually more or less conical in outline. From the crater are ejected—sometimes continuously, sometimes with long intervals of quiescence, but always more or less explosively—gas, steam or water, dust (formed of comminuted minerals or rock), scoria or bits of natural slag, and molten rock or lava. Sometimes there is a well-marked central cone, which crowns a lofty mountain mass." [2] We have seen

[1] J. F. Campbell, *ut supra*, vol. ii., p. 416.
[2] *Story of our Planet*, Part iii., chap. ii.

that a volcano, to a very large extent if not wholly, is built up by ejected materials; that a cone is frequently ruptured and again soldered up by dykes; that it is occasionally truncated by violent explosions; that the greater lava floods are more often emitted from lateral fissures than from the crater itself; and that subsidiary or parasitic cones are common, often in connection with these, on the flanks of volcanoes with a large central cone. We have also seen that the phenomena of an eruption exhibit more or less intermittence, and that not seldom epochs of activity and repose alternate, one of great paroxysmal violence being often preceded by a long period of complete rest. An eruption is generally ushered in by earthquake shocks, is always associated with explosions, and is frequently concluded by the emission of a considerable mass of lava. Great quantities of water are discharged in the form of steam, and the phenomena of an eruption are closely imitated by geysers. Other vapours also are discharged, and the solfatara stage of a dying volcano commonly ends with the exhalation of carbonic acid or some such gas; perhaps the last stage of all may even be a cold mineral spring.

CHAPTER II

THE PRODUCTS OF VOLCANOES

IN the preceding chapter frequent reference has been made, though in general terms, to the materials ejected from a volcano during its more active phases; in the present one they will be described in greater detail. We may divide them into fragmental and massive, though in most cases the distinction is only structural, and does not denote any real difference in the composition of the rock. The former consist of materials ejected by explosion, ranging in size from the finest dust to blocks (occasionally but rarely) even as much as several hundred pounds in weight; the latter of lava, or solidified masses of molten rock, which has either overflowed the lip of the crater, or (more commonly) has issued from some fissure on the side of the cone or the mountain.

In either of these groups the structure of the material ejected will obviously vary in accordance with its environment prior to and shortly after leaving the volcano; but its chemical and mineralogical character will depend upon the composition of the magma from

which it has been derived. It will be convenient to consider the latter first, because it leads us to define a number of terms in common use for descriptive purposes, after which we can readily indicate the principal features in the former by giving short accounts of a number of particular instances.

All rocks which are admitted to have been once molten through heat are called igneous. Those which occur in considerable masses, such as the lavas mentioned above, vary in structure according to the circumstances under which they have become solid. If the process has been rapid the rock, *ceteris paribus*, will be more or less glassy, while if much vapour has been imprisoned in it, and the resistance to expansion has been slight, cavities will be abundant. If, however, the cooling has been more gradual, and the pressure considerable, the rock will be more free from holes and more crystalline. These differences in structural character may exist between the outside and the inside of a lava flow, or of an intrusive mass. Some of these (and among them certain which are more conspicuous at first sight) we pass over for the present, purposing to notice at this stage only thóse which are more directly dependent on the chemical composition of the rock. For convenience of classification an igneous rock is regarded as existing in three conditions — crystalline, semi-crystalline, and glassy. Strictly speaking, this is inaccurate, because there are only two possible conditions for materials of this kind, namely, colloid (glassy) and crystalline.

Of course a glass may be so thickly crowded with crystallites[1] that the mass of the latter may exceed that of the former, but to this we do not refer; for even thus the base or setting of the crystallites is still a glass, though the latter be merely interstitial, and only to be distinguished in a very thin slice and by high magnification. Cases, however, occur, and that by no means infrequently, where, though no glass remains, and definite crystallites are not abundant, yet the crystalline structure is extremely minute, and sometimes presents a peculiar, confused aspect, as though the individual crystal grains had been imperfectly segregated, one seeming almost to "run" into another without any distinct boundary. Under these circumstances the rock, to the unaided eye, or even with slight magnification, exhibits a compact, non-lustrous structure, varying from that of cheese to hard pottery, which it is convenient to distinguish from the other two conditions.[2] Hence it is retained as a distinctive feature in the ordinary nomenclature, and it has the advantage that this becomes an expression of observed facts rather than of hypotheses, which might possibly be called in question. Thus this nomenclature depends primarily on chemical

[1] The word denotes a minute crystal (such as is only visible under a microscope) of any mineral. Microlith is also used for the same thing.

[2] Among other reasons for this we may mention that, in a good many cases, especially among the rocks with a rather high percentage of silica, it is a structure of secondary origin, a form of devitrification, due (at any rate, sometimes) to a process of segregation, which can go on at fairly normal temperatures and pressures if only time enough be given.

composition, and secondarily on the crystalline condition of a rock; the one determining what may be called the generic, the other the specific character, although in petrology a binomial system is not adopted.[1]

The magma of igneous rocks, speaking in general terms, lies between two extreme types: the one consisting of about forty per cent. of silica, nearly as much magnesia, a considerable proportion of iron-oxides, with a small quantity of lime, only a little alumina, and practically no alkalies; the other type contains about double the amount of silica, a fair proportion both of alumina and of alkalies, and only a little of iron-oxides, magnesia, and lime.[2] Several other constituents may be present, but only in very small quantities, rarely equalling one per cent.; indeed, their total amount seldom exceeds this, if we omit combined water, which commonly is found in small amounts, but in some cases has been subsequently introduced. Restricting ourselves to the more important—that is, the more common—kinds

[1] Of late years the spirit of species-splitting has extended from mineralogy to petrology, and has resulted in a host of new names, many of them only varieties. While it is always well to note differences, it is often a doubtful advantage, and sometimes a positive evil, to exalt distinctions over affinities by the coinage of a new name.

[2] I append for purposes of comparison fairly typical analyses of the two extremes:

	SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Alkalies	Sundries	Total
Peridotite . . (St. Paul's Island)	43.84	1.14	—	8.76	44.33	1.71	—	1.60	101.38
Quartz-porphyrite . (Aran Mowddy)	83.80	7.68	.11	.40	.11	.89	6.39	.50	99.88

of igneous rock, we can arrange them in the following groups, which will suffice for our purposes in the present volume:

1. Rocks composed mainly of ferro-magnesian silicates (olivine dominating) and iron oxides (generally with small quantities of chromium). To this group in its crystalline condition the name *Peridotite* is given, and its existence in either of the other forms is not at present established.

2. A very large group, consisting of lime or lime-soda felspars (replaced occasionally by either or both of the felspathoids—nepheline or leucite), together with a considerable proportion of ferro-magnesian silicates, especially augite,[1] and a reduced proportion of iron-oxides. The nomenclature of this group is rather confused. The more conspicuous crystalline forms are called *Dolerite*,[2] and this name should be given to all which are really holocrystalline; but the term *Basalt* is commonly applied to all the kinds which to the naked eye have a compact aspect. Many of these, however, on microscopic examination prove to be really, though rather minutely, holocrystalline. Semi-crystalline rocks of the same chemical composition probably exist, but certainly are not common, for the magma evidently assumes rather readily a crystalline condition; those, however, with a vitreous base are not very rare, and to such as are

[1] In which, as in hornblende, lime also is an essential constituent.

[2] If the felspar is replaced by leucite or nepheline the name of the mineral is prefixed, but sometimes separate titles are given, viz., leucitite and nephelinite.

obviously glassy the name *Tachylyte* is applied. Neither of these varieties occurs in large masses, and the second usually forms only a "selvage" to a flow or to a dyke, and is not more than a very few inches in thickness.

3. A pair of very closely associated but extensive groups, consisting largely of felspars, in which the alkaline earth is replaced to a great extent, if not wholly, by alkalies, and containing generally a rather diminished amount of ferro-magnesian silicates, these being in most cases hornblende or biotite. The two groups are distinguished by the alkali dominant in the felspars.[1] Supposing it to be soda, then the holocrystalline forms are called *Diorite;* the semicrystalline, *Porphyrite;* the glassy, *Andesite.* But if it be potash, then the names given to these three conditions are, respectively, *Syenite*, *Orthoclase-felsite*, and *Sanidine-trachyte.*[2]

4. Another similar pair of groups, the members of which are separated exactly as in the last case; indeed, the main distinction between this and the former pair is due to the higher percentage of silica, and the corresponding lower one of the iron, magnesia, and lime. Thus free quartz is an essential and marked constituent in the holocrystalline forms. The felspars with alkaline bases dominate, sometimes

[1] The soda, soda-lime, and lime felspars crystallise in the triclinic system, and are often called collectively plagioclase; the potash felspar crystallises in the monoclinic system, and is named orthoclase.

[2] Single names are wanted for the second and third, but none exist which, in my opinion, are worthy of adoption.

[redacted]

almost excluding any other; the ferro-magnesian minerals are greatly reduced in quantity, and are frequently represented by biotite alone. Indeed, occasionally they are practically absent, and a white mica is the only constituent of any importance besides quartz and felspar; iron-oxide, however, is almost invariably present, though often in very small amounts. Where a soda-felspar dominates, the holocrystalline rock is called *Tonalite*;[1] the semi-crystalline, *Quartz-porphyrite*; the glassy, *Dacite*. If a potash-felspar, then the rocks are called *Granite*, *Quartz-felsite*,[2] and *Rhyolite* respectively. In both these groups, as well as with the preceding pair, though in them to a rather less extent, semi-crystalline and glassy varieties are comparatively common, and may occur in masses of considerable thickness. The obviously glassy varieties (which, as a rule, belong to the groups rich in silica) are designated collectively obsidians and pitchstones, the former exactly resembling ordinary bottle-glass in lustre and fracture, the latter having a more resinous lustre and a splintery fracture.[3]

Such being the distinctions in the igneous rocks which are due to actual difference in chemical composition, and to the texture of the rock itself, we may leave for the present those which, though in part

[1] Some prefer the name of *Quartz-diorite*.

[2] Often called *Quartz-porphyry*.

[3] Different varieties of lava, from specimens that have some exceptional interest, generally owing to their locality, are figured in magnified microscopic sections on Plates IV. and VII.

dependent on environment, are not necessarily connected, as we shall presently see, with either the former or the latter. We proceed then to describe the materials ejected by volcanoes, and commence with those of a fragmental character, since they have the briefest history, and thus afford fewer opportunities for any mistake as to their origin.[1]

Mr. Whymper, as already mentioned, spent a night on the summit of Cotopaxi.[2] Next morning his tent was covered with dust, so that it had become a dusky-grey colour. This evidently had been ejected from the crater by the steam-blasts, in which, however, even during the daylight, there had been no visible admixture of solid particles. It has been described in the following terms[3]: "A grey dust with rather darker specks. The grains range from .02 inch in diameter downwards, a considerable proportion varying between this and about .01 inch. They may be distinguished into rock fragments and mineral fragments. The former are partly chips of colourless, or nearly colourless, glass, sometimes almost clear, sometimes clouded with ferrite or opacite, and containing microliths of felspar, etc.,—chips, in short, of glassy lavas, such as occur elsewhere on the mountain—partly of rough, opaque, or nearly opaque, grains, rather more numerous and larger in size than the chips, sometimes translucent at the edges, and includ-

[1] All the specimens described are in the author's collection. Plates III., IV., and VII. illustrate the microscopic character of lavas and rocks.

[2] See page 40.

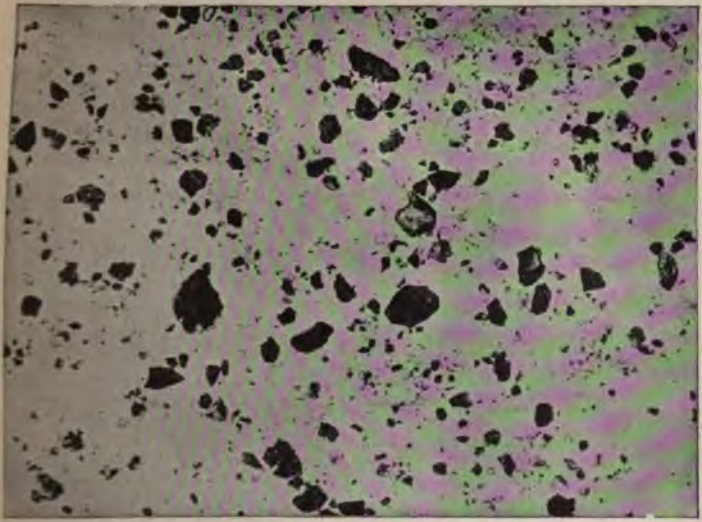
[3] *Pro. Roy. Soc.*, vol. xxxvii., p. 123. See Plate III., fig. 1.

ing microliths of felspar and augite." These grains, when examined by reflected light, have a scoriaceous exterior, and are greyish, blackish, or reddish-brown in colour, being evidently minute lapilli of an andesitic lava. The mineral fragments are felspar (showing occasionally plagioclastic twining) and, more rarely, augite; perhaps also hypersthene. Fragments, both of glass and of minerals, may be detected even among the finer dust, together with black specks, probably magnetite.

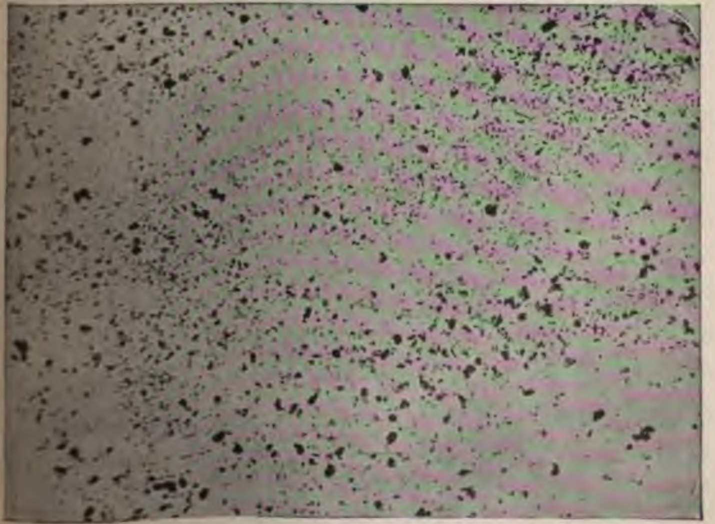
The next specimen to be noticed is also from Cotopaxi, but it had travelled farther than the last, for it was collected by Mr. Whymper, as already described, on the summit of Chimborazo.[1] It is a fine dust of a slightly paler and redder colour than the last, and the constituent grains are distinctly smaller, only a very few attaining to a diameter of .01 inch, which is barely exceeded. Fragments measuring from .003 to .004 inch are common, and they descend from this size to the finest dusts, the characteristic of the deposit apparently being the presence of grains ranging from about .001 to .003 inch. As in the other case, they consist of both rock fragments and mineral fragments; but among the former the rough dark lapilli are rare, the majority being chips of glass, apparently smooth externally, commonly of a pale brownish colour, in which acicular microliths, probably of felspar, are frequent, with specks of ferrite, and possibly a granule or two of a pyroxenic mineral; vacuoles are

[1] See page 42, and Plate III., fig. 2.

PLATE III. DUST EJECTED BY COTOPAXI (x 25).



(1) Collected on summit of the volcano.



(2) Collected on summit of Chimborazo.

certainly rare. The mineral fragments are felspar, with a little augite, and certainly one well formed though tiny hypersthene crystal. Fragments of felspar and acicular crystallites are rather abundant among the finer dust.[1]

Several other volcanic dusts collected by Mr. Whymper in the Ecuadorian Andes differ only in detail from the above described, so that we may pass on to some which exhibit rather more marked variation. One, which I select as characteristic of the detrital condition of a "frothed up" form of glassy lava, is a sample of the dust, ejected from Krakatoa, which fell at Batavia, at a distance of ninety-five miles. This dust contains mineral fragments, such as plagioclastic felspar, augite, hypersthene and iron-oxide, with numerous rock fragments; but these differ from the above-described dusts of Cotopaxi in the presence of bits of very light brown fluted or possibly porous glass. These have been produced by the destruction of the vesicular pumice, which, as already mentioned, was so copiously ejected. The latter, under the microscope,[2] is seen to be a vesicular, almost clear, glass, "like some viscid fluid 'whipped' to a foam and then allowed to flow." Minute but distinct chips of this pumice may be occasionally recognised in the dust.[3] Dust from the great eruption of Tarawera, in 1886, was collected at Matakava,

[1] *Pro. Roy. Soc.*, vol. xxxvii., p. 312. [2] See Plate IV., fig. 1.

[3] Prof. Judd, "Krakatoa Report," *Royal Society*, p. 38, describes the dust and how it would be sorted out in passing through the air. The samples examined by him had travelled various distances from 40 to 1100 miles.

Hicks Bay, New Zealand, after a journey of 115 miles. It consists partly of darkish scoria, often about .005 inch in diameter, ranging from that to .008 inch; frequently smaller than the former, but rarely exceeding the latter, though one bit attains .012 inch; partly of chips of glass, colourless to light brown, seldom exceeding about .005 inch, and from that to very minute; partly of mineral fragments (less abundant), most of them felspar, probably nearly allied to oligoclase, with a very little hornblende and perhaps a minute flake or two of brown mica.[1] Some pieces enclose small vesicles; many show ridges indicating that they are the *débris* of pumice. Chips of colourless or nearly colourless pumice, which often exhibit the ribbed or fluted aspect[2] mentioned above, are not infrequently found in examining sedimentary rocks, and bands of volcanic dust may occur in regions far away from any vent, as, for instance, has been observed at Barbadoes.[3]

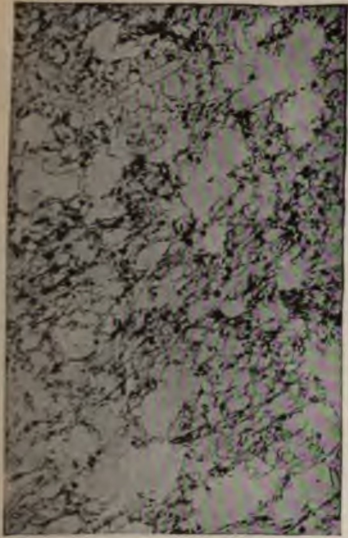
Occasionally the detrital material of a volcanic eruption consists almost entirely of glass fragments. So it was with a dust of Niua-fu, collected in 1886 after a violent eruption. No quantity of coarse material appears to have been discharged to any distance, but the island was almost smothered by fine

[1] *Nature*, vol. xxxv., p. 56.

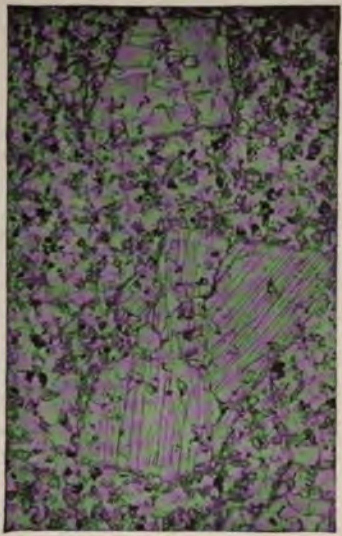
[2] Probably indicating the broken wall of a vesicle, or at any rate a projecting "rib" of glass.

[3] A. J. Jukes-Brown and J. B. Harrison, *Quar. Jour. Geol. Soc.*, vol. xlviii., pp. 180, 192, etc. (Report by Miss C. A. Raisin). In May, 1812, volcanic dust fell in that island which came from the Soufrière of St. Vincent, nearly 120 miles away.

PLATE IV. SECTIONS OF VOLCANIC ROCK (x 25).



(1) Pumice from Krakatoa.



(2) Lava from Vesuvius, 1631.

(3) Old lava-flow (rhyolitic), Cwm-y-Glo, near Llanberis.

(4) Lava, Kau, Hawaii, Sandwich Is.

dust, which did great injury to vegetation. The fragments of this rarely exceed .03 inch, and commonly range from that to .01 inch, though, of course, smaller material is also present. About the latter size they are fairly translucent, and a rich brown colour; about the former, opaque, except sometimes at an edge. Cavities, ovoid or spherical, are not infrequent; enclosed microliths are rare. Many fragments exhibit ropy folds or the remains of a cellular structure, showing that they are due to the destruction of a very vesicular glass. Perhaps from two to three per cent. of the chips are felspar (the only mineral). The rock is a tachylite, and its specific gravity is 2.726 (including the felspar). The island, which is about forty to fifty miles round, is wholly volcanic, having a central lake in which are some small islands. The eruption took place at one end of this.[1]

The glass of a pumice rich in silica, such as that of Krakatoa, is often drawn out into fine threads like spun silk, as may readily be seen on examining the interior of the cavities, and this material, from its brittleness, must often largely contribute to the constituents of the dust. Sometimes, however, the glass, by the action of the escaping jets of steam, is actually drawn out into long, hair-like filaments, resembling the "spun glass" which was made for the delectation of juveniles in the old days of the Polytechnic. Kilauea is noted for manufacturing this material, which is there called Pele's hair, that

[1] See *Nature*, vol. xxxv., p. 127, where a fuller description is given.

being the name of a female member of the Hawaiian pantheon, the equivalent of the classic Venus. "In the jetting and splashing of the lavas the flying clots and drops pull out the glass into hairs, just as takes place in the drawing apart of a glass rod when it is melted at the middle. Mr. Brigham says the drops of lava thrown up draw after them the glass thread, or sometimes two drops spin out a thread a yard long between them."[1] According to C. F. W. Krukenberg, to whom Dana refers, the glassy fibres are sometimes forked or branching, sometimes welded at crossings, and often contain air vesicles, which are apt to be drawn out into tubes, and occasionally enclose microscopic crystals. The hair, when gathered in a tuft, is a light greenish-grey colour.[2] This glass, however, is not rich in silica.

In certain cases, where the lavas from a volcano, as will be presently described, contain crystals large enough to be readily seen with the naked eye, fragments of these will be found among the coarser materials of the cone itself. For instance, the lava of Vesuvius often contains crystals of leucite, augite, and olivine, and fragments of all three, at least as big as hemp seed, may be readily gathered on the edge of the crater. On the Puy de la Solas, in Auvergne, one can pick up augite ; in short, broken minerals of fair size are not rare among volcanic detritus.

[1] Dana, *Characteristics of Volcanoes*, p. 160.

[2] It bears a very close resemblance to the slag-wool formed by blast-furnaces. In my cabinet, boxes containing this and Pele's hair lie together, and the one might well be taken for the other.

Proceeding to the rock fragments of larger size, which make up the larger part of the ejected *débris*, we find that these go by a variety of names, none of which admit of very precise definition. If the material is very cellular, so that the volume of the vesicles considerably exceeds that of the solid, and the walls between the cavities are thin,—a structure associated, as a rule, with a very glassy condition of the rock,—then it is called pumice. If the vesicles are generally small, irregular, and less numerous, and the lump itself is rough and "cindery" in aspect, it is called scoria. The cavities themselves may be large or small, but the latter is more usual, and they are commonly irregular in size. A piece of scoria—except for the colour, which is very diverse, for it may be almost anything from a cream-white to a dark tint, such as reddish, purplish, brownish, or blackish—is not unlike a piece of "pulled bread," though generally it is rather more cellular.[1] Where these cavities are not only few, but also rather irregular in size and distribution; where the rock itself is compact and more or less vitreous; where its exterior is less rough and inclined to be "ropy" in aspect, it is called slaggy, from its resemblance to the slag of a smelting-furnace. The fragments, whether rough or smooth, which a volcano has ejected, vary greatly in size; they are, to use the well-known saying, "as big as a lump of chalk." Beginning with the microscopic size described at

[1] A rock with these characters is said to be scoriaceous, and with the preceding, pumiceous.

the outset (which, however, are commonly not intended when the terms just defined are employed), they get bigger and bigger, till sometimes they attain a volume of several cubic feet. But, as a general statement, we may venture to say that they commonly range between a pea and something rather bigger than a man's head. Lumps distinctly larger than the rest, which often fall as solitary projectiles, are sometimes called volcanic bombs. They vary greatly in shape, and it is not seldom evident that they have been ejected in a liquid, or at any rate pasty, condition, and have been modified in form during their flight. Small fragments, say not more than an inch in diameter, are often called *lapilli* or *rapilli*; if fragments of rather larger size, occasionally about three inches in diameter, are mixed with these, the mass is frequently spoken of collectively as an ash; when still bigger blocks occur, and the structure is apt to be very irregular, so that blocks of all sizes are tumbled together, the mass is called an agglomerate. This, of course, will only be found very near to a volcanic vent, though now and then a solitary big block is hurled to a rather long distance. The finer materials, when pretty regularly stratified by the action of water, are called tuffs.[1]

The cavities vary greatly in size and in form. They may be either microscopic or several inches

[1] The term "tuff" is sometimes applied to masses of carbonate of lime precipitated from water, but it is better to restrict the name of tufa (with travertine) to these, and tuff to volcanic materials when stratified.

PLATE V. FRAGMENTS EJECTED BY VOLCANOES.

(1) Basaltic scoria, The Eifel.

(2) Basaltic bomb, Auvergne.

in the longest diameter. The most regular are spheres, spheroids, or ellipsoids. They are formed, of course, in homogeneous, pasty material by the outward pressure of confined vapour. If the mass moves after the vesicle has been formed, then this is more or less elongated. Sometimes numerous tubes may be observed in a lava perhaps a quarter of an inch in diameter and three or four inches long. This is often called a "pipy" structure. But very commonly the cavities are extremely irregular in shape. Probably this is due to a combination of causes: inequalities in the temperature and consequently in the hardness of the mass; inequalities of pressure and strain due to its environment and movements; perhaps also inequalities in the amount of water present in it. To this we may add the rupture of thin partitions between adjacent vesicles. Even in the same mass, though usually the cavities are either fairly regular or distinctly irregular in shape, both types may occur. These cavities obviously cannot be formed until the magma has become stiff enough to prevent the molecules of water from passing freely through it, though it must still be plastic enough to give way to their pressure. Strains set up as the lava goes on cooling may produce further bendings and ruptures, and may still more modify the form of the vesicles.

But fragments of sedimentary, metamorphic, or crystalline rocks are sometimes ejected by volcanoes. An explosion may shatter the top crust of stratified

deposits and hurl the materials into the air, as clods and splintered stone fly when a mine is discharged. This, of course, is most likely to occur at the first outbreak of a vent, and the result will be most readily observed when the discharges have been small, for otherwise it is probably hidden beneath later ejections. In some of the *débris* from the Eifel volcanoes bits of shattered slate frequently form a considerable fraction of the whole mass. Sometimes these are not perceptibly altered, but occasionally they are fused at the edge, as if by the action of a blow-pipe. But in other cases the alteration is more complete. Blocks of white crystalline marble are common among the heaps of ashes, or even lie loose on the slopes of Vesuvius. Sometimes they contain certain silicates, such as a pale-coloured augite, idocrase, mica, etc., while other specimens are as pure as statuary marble. There can be little doubt that they represent the pale-coloured limestones[1] which are exposed on the outskirts of the volcanic region, and that the alteration has been an effect of the local high temperature combined with considerable pressure.[2] Fragments of various sedimentary rocks, more or less altered, are sometimes included in lava streams or in big lumps of scoria. These also have been torn off, either from the side of the "throat" of the volcano by explosions, or from rocks shattered by the lava in forcing

[1] They are of Secondary age, some about that of the chalk of England.

[2] For pressure, as proved by Sir James Hall's experiments, causes calcite to assume a crystalline condition instead of being dissociated into carbonic acid and calcium oxide.

its way to the surface. Fragments of crystalline rocks also occur, sometimes from such as are of doubtful origin, like mica-schist or gneiss ; sometimes from indubitable igneous rocks, such as granite, diorite, dolerite, or peridotite. In certain cases the presence of these is easily explained, because the rocks represented by them are seen to occur at the surface, or are known to exist at a comparatively short depth below it. But in other cases they must have been brought from great depths, because their coarsely crystalline structures indicate that the masses from which they came cooled slowly and under very considerable pressure. In the Eifel, for instance, it is not unusual to find embedded either in a volcanic bomb or in a lava stream fragments of peridotite, a rock which, so far as we know, has never reached the surface as a lava or been ejected as scoria. Of course fragments of various kinds are not seldom common in intrusive masses of lava, as well as in other kinds of igneous rock ; but to this we can more conveniently refer in a later chapter.

One peculiar variety of scoria, described under the name of thread-lace scoria by the late Professor Dana,[1] may be mentioned before we quit the subject. It occurs as a layer 12 to 16 inches thick over the southwestern border of Kilauea, and in one or two other localities in Hawaii. It is a spongy, glassy scoria, in which the vesicles are ninety-eight to ninety-nine per cent. of the mass, the walls in the coarser varieties

[1] *Characteristics of Volcanoes*, p. 163.

[redacted]

being sieve-like, or reticulated, in the finer, like thread-lace in structure. Obviously it has been formed from a lava which was so full of steam as to have been regularly "frothed up," so that the party walls between the expanding vesicles have been attenuated till they burst at the thinnest parts.[1]

The rock of which all these fragments—lapilli, scoria, etc.—are formed, when we study it without regard to the cavities, is, of course, identical with that in adjacent lavas, except that the latter, as cooling in larger masses, are likely to offer a greater variety of structure. These structures, however, we put aside for the moment, since they can be more conveniently discussed after a brief description of a lava stream. As in the case of the fragmental material, so here, the term lava does not define the rock's chemical composition, though at present we do not know of any lava belonging to the peridotite group. There are acid and basic lavas,[2] often designated distributively trachytes and basalts. The exterior portion of a flow, especially on the upper side, is generally more or less cellular. Sometimes this structure extends throughout the mass, particularly if that be rather thin, but at other times the rock remains compact to within a very few inches of the margin. Usually the cavities in the more central part of a

[1] Fragments of this structure may sometimes be detected in examining volcanic dusts under the microscope. The threads, of course, are not round, but are bounded by incurving surfaces and portions of spheroids or ellipsoids.

[2] Lavas are said to be acid when their silica percentage is sixty or more; basic, from about fifty-five downwards.

[redacted]

moderately thick stream are small in dimensions, though to this there are exceptions. The volume, however, of the solid part, as a rule, greatly exceeds that of the cavities.

The surface of a lava stream is found on examination to exhibit a great variety of structures. These, however, may be divided, as a rough-and-ready classification, into two fairly distinct types,—the slaggy and the "clinkery," or scoriaceous.[1] The surface of the former is smoother and more glassy; it is often wrinkled with the curving lines of viscous flowing; it has a "ropy" aspect, resembling a lot of entangled cables, or a heap of gigantic slugs crawling one over another.[2] In parts the surface becomes rougher; here bits of lava seem to be tossed up into the air like petrified spray; there sheet has flowed over sheet, or a solidified crust been left standing to form a rude grotto in consequence of the escape of its still fluid contents. Often the surface of one of these lava streams is cracked; sometimes it is traversed by great rifts; here and there huge blocks seem to have

[1] The late Professor Dana, in writing of these lavas (*Characteristics of Volcanoes*, p. 9), gave them the names which they bear in the native language of Hawaii; calling the former *pahoehoe* (meaning a satin-like aspect), the latter and rough kind, *aa*. The terms are creeping into scientific books, but they are as needless as they are barbarous, and add nothing to the plain words, slaggy and clinkery, or—if this seem too homely—scoriaceous. To some students words unintelligible to ordinary folk seem to be just as alluring as the slang of a public school is to the boys. It is bad enough when geological literature is flooded by bastard Greek terms, but it is time to protest vigorously when recourse is had to the language of an insignificant and uncivilised race in a small archipelago in the North Pacific.

[2] See Plate VI., fig. 1.

been thrust forward and to have toppled over. The surface of the second type is rough and irregular in the extreme, just like a mass of continuous scoria.[1] In fact, it would often be impossible to distinguish a fragment of the crust from a broken piece of scoria unless one knew how it had been obtained. If indeed it has chanced that showers of the latter have been ejected while the stream was still flowing, so that some of them have adhered to the pasty mass, it often becomes very hard to say what is true lava-crust and what is adherent scoria. In short, the surface of one of these streams is all ups and downs, ridges, fissures, waves, projections, jags, and tatters. Slip on it you hardly can; scratch and scrape yourself if you fall on it, nay, even if you grasp it too hurriedly, you certainly will. Of course, as we have already said, the one type of lava gradually shades off into the other, and sometimes each may occur on different parts of the same flow.

Occasionally we find scoriaceous portions at a fair depth in a compact lava-stream. Sometimes this may have been produced by the lava having been emitted in successive jets, whereby one liquid mass has flowed over the first solidified crust of its predecessor, and has become partially fused to it; sometimes, when very limited in extent, it may be due to the accidental excess of entangled vapour at a particular spot, but perhaps more often it is the result of a temporary check in the movement of a lava stream.

[1] See Plate VI., fig. 2.

PLATE VI. LAVA STREAMS.

(1) Slaggy (Vesuvius, 1858).

(2) Scoriaceous (Etna, 1886).

The front ceases for a while to advance and "freezes" over. The pressure from behind on the enclosed liquid gradually increases, until at last the stony crust is burst and its fragments are enveloped and borne along by the fluid mass as it renews its onward movement.

To some such cause another structure not infrequently seen in lava-flows is due. It is rather common in members of the acid group, but very rare among the basic. It assumes more than one form, but these all are closely related. Sometimes the fractured surface of a compact trachytic lava appears like a breccia, angular or sub-angular clots being set in a matrix of different tint. It is in reality a kind of breccia. A fluid lava, whether before or after its emission from the earth, has encountered a mass which has practically become solid, has broken it up, and has swept along the fragments like curds in whey. If the curds have been only in a pasty condition, or if they have been much softened by the heat of the irruptive magma, in some cases they are partially remelted, in others they are more or less drawn out as they are dragged on by the advancing mass. This process very commonly is carried so far that the two magmas have become regularly "interstreaked," exactly as we may see occur in some slags, or when glasses of different colours have been formed into a stripy mass. This is called fluidal[1] or fluxion

[1] This structure, however, might also be a result of movement in a mass in which differentiation, as explained in a later chapter, has taken place. (See

structure; the name of flow-brecciation being often given to it when in the first stage.

We may mention, in this connection, two structures occasionally exhibited by a lava stream. One is the building-up on its surface of small cones composed wholly, or almost wholly, of lava. They are evidently due to the escape of steam or gases from the still liquid interior through a crack in the crust. They occur in several places, but seem to be rather frequent in the Ile de Réunion. The annexed sketch represents a lava cone in actual eruption, discharging steam (though not in large quantities) and ejecting small bombs from a shallow crater at the top, while it kept adding to the cone by little spurts of lava. But this volcano only attained a height of about thirteen inches, and it was formed on the surface of a truck

FIG. 7. WORKING MODEL OF A LAVA CONE.

Plate IV., fig. 3, for its aspect.) In this case the matrix has assumed (no doubt subsequently) a semi-crystalline structure.

of slag from a smelting-furnace at the Crewe railway works. It was, in fact, a working model of one of these Bourbon lava cones, the making of which it probably would not have been so easy to watch. Occasionally the jetting lava builds up for itself a kind of funnel, as if the mound terminated in a chimney. Caverns are sometimes formed in a lava stream, probably by rupture of the outer skin and the sudden escape of a quantity of liquid material, which it has held back for a time. This, of course, requires that a more or less lenticular portion of the lava close to the exterior of the stream should be more liquid than the rest.

Lava, which freezes as it flows, may assume a stalactitic form, as water makes an icicle of irregular shape, driblet after driblet becoming solid as the fluid oozes from a crack in the hardened "skin" of the mass, or as the glowing flood descends in a cascade over a craggy step. M. Vélain, in his interesting account of the Ile de Réunion,[1] gives a figure of a cavern in the lava, formed as has been already described, the roof and walls of which are covered with pendent lava stalactites, far surpassing in abundance those of any cave in Cheddar or Derbyshire. Certain examples, however, which have been described by Professor Dana, from the Sandwich Islands, are yet more slender in form and difficult of explanation.

[1] *Description géologique de la presqu'île d'Aden et de l'Ile de Réunion*, etc., Fig. 15. At Fig. 16 also is a sketch of a monticule of lava with a small cavern at the foot. In both cases the lava is evidently of a very slaggy nature.

The account of these may best be given in his own words[1]: "Perhaps the most interesting and remarkable formations connected with the lava-flows from Mauna Loa are the delicate stalactites and stalagmites of lava which occur in the caverns. The specimens in the collection [of which figures are given] are mostly from a cavern in the lava stream near Hilo. . . . Figures of some of the forms of similar stalactites from the caverns of Kilauea are given by Brigham. . . . According to the accounts given, the flowing lava-stream, crusted over at the surface, leaves behind it, when the molten material has flowed by, long caverns, usually five to ten feet in height, having a roof of one to three or more feet in thickness, and a floor of the solidified lava. In the caverns are found hanging from the roof the slender lava stalactites. In the Hilo cavern they were from a few inches to twenty or thirty in length, and in some places only six to eight inches apart. The diameter, which seems to have been determined by the size of the drop of the liquid material, does not vary much, being usually about a quarter of an inch. Beneath the stalactites, from the floor below, rise the clustered groups of the stalagmites. These delicate forms are so fragile that they hardly bear transportation. . . . Some are straight and nearly uniform; others are curiously gnarled and knotted, especially near their lower extremities. The end has often a little process thrown

[1] *Characteristics of Volcanoes*, p. 332.

off at right angles—a little hook or close spiral of two or three turns, often tangled or knotted together. The simple rods are usually round, not often flattened, except when there is a sudden change in direction, when they may be pinched together like a glass tube bent when hot. The surface is exquisitely ornamented with most delicate markings. The stalagmites, formed by the droppings from above, are intricate clusters or piles of simple drops several inches in height. . . . The exterior of the stalactites has usually a more or less bright metallic lustre, and though sometimes dull and granular, the surface often reflects the light brilliantly from a multitude of crystalline facets; these sometimes separate into distinct scales, shown to be largely hematite by their reddish streak, though magnetite is also present. . . . Sometimes the metallic covering is very thin, or is not continuous, forming patches on a brown surface." This surface, he proceeds to describe, is more or less continuously ornamented with delicate transverse ribbing or cording, like the most minute ripple marks. "The straighter portions of the stalactites are often solid throughout, though here and there they are hollow and consist of a mere shell. Portions that are perfectly solid frequently alternate with the cellular parts, or the solid parts contain a series of large vesicles. . . . The explanation of the process by which these unique volcanic icicles have been formed is not easy to give. . . . It seems at first most easy to think of them as made by the rather

rapid dripping of the semi-viscid lava from the roof. The evidence at hand, however, shows pretty conclusively that they could not have been the result of simple direct fusion. The fact that they hang down from the solid crust, while the stalagmites formed by the dripping from above rise from the solid floor, seems to prove that they were formed after the molten lava had passed by and the temperature had fallen below the point of fusion. If made directly from molten material they could hardly be so perfectly crystalline throughout as they have been shown to be. We should expect them to be more like the glassy spatterings from the blow-holes of Kilauea mentioned in a former page. Moreover, the sorting out of the material is further evidence on the same side—the crystalline shell of hematite and magnetite, with its lining of augite, and, within, the solid crystalline mass, or the clusters of beautiful crystals chiefly of felspar. Still again, the question has been raised as to whether the flow of a viscid liquid like molten lava could form drops so small as the size of the stalactites shows must have been present.

"The fact that the lava rods or tubes of the stalactites are of nearly uniform size throughout their length, although bunched and knotted together at frequent points, as has been described, is an important one. It separates them, as to mode of origin, from the stalactites of a limestone cavern, which form in a more or less conical shape from the flow down

over the exterior surface of the lime-bearing solution. It seems to require that the shell should have formed first, and that these tubes should have lengthened by the material carried down within them, finally resulting in their becoming solid to a greater or less extent. This is confirmed by the fact that the parts seemingly most solid often prove to have at the centre minute crystal-lined cavities. The lengthening by the addition of material at the point of attachment above, the only other method that can be suggested, is difficult to conceive of.

"As the facts at hand are inconsistent with the theory of a direct formation from the melted condition, we are forced to speculate as to the power of the highly heated water vapour, known to be present in large quantities, to form them from the roof by a sort of process of aqueo-fusion. This is a subject about which we know too little at present to make speculation very profitable."

It is undoubtedly most difficult, as Professor Dana observes, to explain the origin of these stalactites. Speaking for myself I do not attach so much weight as he seems disposed to allow to the external glaze of iron-oxides, for these appear to occur not uncommonly on the exposed surface of glassy basic lavas, and may be produced by an oxidation of the ferrous constituents in that part of the liquid magma which is brought into contact with the air while still at a high temperature. The description both of the minerals present in and of the microscopic structures

of these stalactites, and the small figures of thin sections which are given by Professor Dana, seem to indicate that the material in these stalactites is identical with certain parts of a basaltic mass which has been rapidly cooled. Throughout nature, as a general rule, differences in mode of origin are expressed by a difference in structure, and so far as I can form an opinion from the evidence so carefully presented in the above quotation, I should infer that the solid parts of these stalactites had been formed very much in the same way as the slaggy crust of a basalt-flow. But their position seems to require that we assume this crust to have become solid, or very nearly solid, when they were formed, and if that be so it is difficult to understand, even making every allowance for the bad conductivity of a lava-crust, how a layer, which seemingly was for the moment as liquid as treacle, could exist immediately within it. As, however, we can hardly suppose these stalactites to be the result of a distinctly subsequent deposition of mineral matter, which has been derived from the solidified basalt as are the pendants of calcite in a cavern from the overlying limestone, we cannot neglect the possibility that the fusibility of the magma may have been locally increased owing to the action of steam, the escape of which has been checked by the sudden freezing of the external crust. But be this as it may, and we cannot do more than conjecture, these basalt stalactites seem to indicate the presence of water in no inconsiderable quantities in the liquid

magma, a point to which reference will be made later on, and to show that in nature the process of fusion in the igneous rocks differs in a very important respect from that which occurs either under the action of a blow-pipe or in the smelting-furnace.

In the course of cooling, certain constituents—at any rate, in many lavas—crystallise out and form distinct minerals. The size of these depends partly on the nature of the lava, partly on the circumstances of cooling. Other things being the same, the more slow and gradual the fall of temperature the larger are the minerals which are formed. Thus it is not uncommon to see that a mass of lava, which is glassy at the very outside, is compact and stony within, or that small crystals begin to show themselves near the surface, which increase in size in proceeding away from it. Crystals, however, which appear under these circumstances are never at all large, whatever may be the mineral; but sometimes we find in compact or even glassy igneous rocks, whether flows or dykes, or intrusive sheets, quite big crystals; and these do not vary in size in different parts of the mass, nay, sometimes may even be found entangled in its scoriaceous exterior. A pitchstone which occurs on Goatfell (Arran) is crowded with crystals of felspar, often quite half an inch long; crystals of sanidine, almost a couple of inches long, abound in the trachyte of the Drachenfels and other parts of the Siebengebirge, and they are nearly as long on the Puy de Sancy (Auvergne). Carlsbad twins of orthoclase, even larger, occur in the

"porphyroid" of Mairus in the Ardennes[1]; big crystals of augite in the basalts of more than one locality; leucites, occasionally nearly an inch in diameter, in some of the lavas of Vesuvius. The origin of what is called a porphyritic structure in these and many other like cases can be discussed more conveniently in a later chapter; at present it may suffice to say that such crystals were not formed during the final consolidation of the rock, but had separated out from the lava before it reached the surface of the ground, so that at the time of ejection it consisted of crystals and fluid.

In this connection another crystalline structure may be mentioned, which sometimes, though not always, is set up during the consolidation of the mass. It consists of little balls called spherulites, formed of innumerable small needle-like crystals, diverging radially from a centre. Commonly they are quite small, like mustard seeds or peppercorns, though they not seldom attain to the size of peas or small cherries, and occasionally are even an inch or two in diameter. In the last case they are apt to be rather less regularly spherical and to exhibit a less distinct radial structure. They are then often called pyromerides. The smaller sometimes are formed round a little crystal as a nucleus; the larger not seldom enclose cavities.[2]

[1] This is a true igneous rock, and probably an intrusive mass. There is no valid ground for explaining the typical porphyroids of the Ardennes as metamorphosed sediments.—*Proc. Geol. Assoc.*, vol. ix., No. 4.

[2] Some authors maintain that the cavity is produced by a rotting away of the inner part of the spherulite. My own researches have led me to the conclusion

PLATE VII. SECTIONS OF VOLCANIC ROCK (x 25).

(1) Kilimanjaro.

(2) Aconcagua.

(3) Chimborazo.

(4) Elbruz.

Another set of structures must now be noticed, due indeed to cooling, but of mechanical, not of mineral origin, namely, the various forms of jointing. As a mass of rock passes by loss of heat from a fluid to a solid condition it gradually contracts. So long as the molecules can move freely the diminution of volume proceeds without any rupture of the mass; but when it is more nearly a solid, the strains which are set up

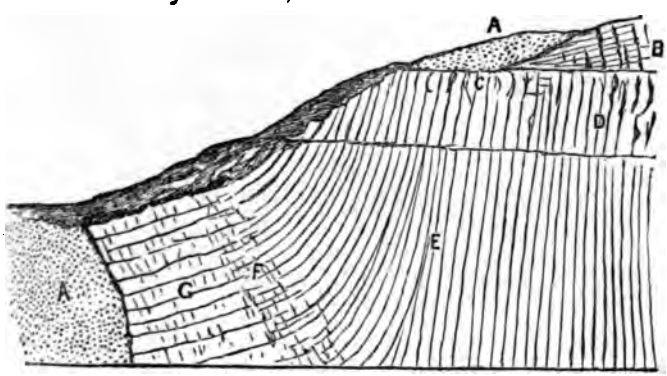


FIG. 8. JOINTING OF MASS OF INTRUSIVE BASALT, GROSS WEILBERG, SIEBENGEBIRGE.

A, trachytic tuff; B, closely jointed rude columns; C, bent columns, rather rude; D, upper stage, E, lower stage, of quarry, good columns; F, platy structure; G, the same, affecting the rude columns.

ultimately cause fracture. For each kind of rock there will be a certain temperature at which this effect will be produced under the given circumstances. The surface then, in which at a particular moment all points are situated which have reached this temperature, will be a surface of "breaking strain." Towards

that in most cases, if not in all, the cavity was there when the spherulite was formed.

the outside of a mass, owing to a variety of causes, this surface will assume an extremely irregular form; the loss of temperature also will be rapid. Hence the exterior part is generally traversed by numerous and very irregular cracks. They vary in size and depth. In many cases they are not large, a few feet in length and one or two in depth; but occasionally they become much greater, and the lava stream is rent by fissures almost as a glacier is by crevasses. But beyond the zone of irregular fracture, or if the loss of heat be more uniform, as will often happen near to the outside of an intrusive mass, such as a dyke, the surface of uniform temperature quickly becomes a plane parallel with the external plane, or, in other cases, is a curve similar to that of the boundary surface. Here, however, the loss of heat may be rapid; if so, there is a greater strain between the molecules in successive layers than between those in the same layer; hence the surfaces along which rupture takes place are more likely to run parallel with the exterior than perpendicular to it. Thus a platy structure is commonly the first product of the strain of cooling when it has begun to act with considerable regularity. But when the loss of heat is very gradual and uniform, owing to the existence of a moderately thick external crust of material, which, as is the case with all lavas, is a bad conductor, then the lateral tension caused by contraction becomes the more effective, and so the planes of rupture are perpendicular to the external surface. Under these circumstances hexa-

gonal forms of considerable regularity are often produced, this being called columnar or (incorrectly) basaltic jointing. It does not fall within our present purpose to discuss the explanations both of the different forms of jointing and of the frequent occurrence of this hexagonal type: enough to say that it results from the principle of least action. As shown by the late Mr. Mallet, there are only three regular forms into which plane space can be divided, namely, equilateral triangles, squares, and hexagons, and the amount of work which has to be done in producing these is given approximately by the ratio 100 : 68 : 52. So the last of the three requires the least expenditure of force. If the strain in any two directions at right angles one to another is not quite equal, then the fissure in one direction will be more pronounced than in the other, and master joints, as they are called, will be the result, which give a more tabular shape to the blocks.

When a prismatic structure is set up, particularly if it be hexagonal, the columns sometimes extend for several feet without further fracture; but very often as they continue to cool and contract they break across, and the column instead of being a monolith resembles one built of masonry. Associated with this a peculiar structure, called generally "cup-and-ball," is often found, where the surface of a cross joint instead of being flat is curved; sometimes a sort of dome (as on an Oriental house) rises from the flat top of one "vertebra" of a column, and fits into a

corresponding hollow in the next one.[1] A complete explanation of all the variations of this structure is far from easy, but it is undoubtedly another result of contraction in cooling, for a sphere, by parity of reasoning to that employed in the former case, is the shape most easily produced in any solid, which is in a uniform state of strain in three directions at right angles one to another. That is the origin of the spheroidal structure commonly seen in compact igneous rocks, especially basalts, which becomes more distinct when the rock is rather weathered. It is also often seen on a very small scale in pitchstones and obsidians, but then it is called perlitic structure.[2]

FIG. 9. SPHEROIDAL STRUCTURE IN AN UNJOINTED COLUMN OF BASALT, NEAR LE PUY, AUVERGNE.

We have thus acquired from our inspection of regions where volcanoes are still active some knowledge of the materials which are ejected, and of the mode in which these are accumulated. The fragmental vary greatly in size, and exhibit sudden changes. When they are chiefly coarse they are piled up in a rather irregular fashion over a limited area; the finer as a rule are more widely distributed and more evenly stratified, but these are not likely to oc-

[1] See Plate VIII., figs. 1, 2, for varieties in column structure.

[2] See paper by the Author, *Quart. Journ. Geol. Soc.*, vol. xxxii. (1876), p. 140.

(1) A mass of basalt and curved cross-joints.

(2) Columns and cross-joints.

cur in thick masses. The stratification of the coarse materials will be irregular, like that of a talus-heap from a mine or a quarry, larger and smaller fragments sometimes occurring pell-mell together, sometimes roughly sorted out into layers, which, however, generally can neither be traced very far nor are regularly disposed. We have further endeavoured to obtain an idea of the general aspect and structure of lava streams, and of the criteria by which they can be identified. We also notice that, as we might expect, no very great difference exists between the rock of a flow and of a dyke, except that the latter is less likely to be vesicular, has usually a smoother surface, is often more compact or more distinctly crystalline, and is never properly interbedded with scoria, etc., though it may have forced its way through or between them. Besides all this, an intrusive mass of heated rock produces changes in the strata above and below it, while a lava-flow obviously can only alter the underlying one. Hence we can apply this knowledge to the interpretation of regions in which volcanic action has been long extinct, where the action of denuding agencies has destroyed, in part or wholly, craters and cones, and we are thus enabled to study the anatomy of volcanoes in the dissecting theatre of Nature.

CHAPTER III

THE DISSECTION OF VOLCANOES

NO district readily accessible from England offers better opportunities than Auvergne for the study of volcanoes which, so to say, have but recently expired. Here are craters so perfect that the last shower of scoria might have fallen only a few centuries ago, and lava-flows which might have been still steaming in the days of Hugh Capet. Yet almost side by side with these are other cones and other flows in various stages of dismemberment: craters wearing down into mounds, cones scarred and furrowed by the weather, sheets of lava deeply cut by streams, even carved into bastion-like prominences and insulated plateaux, or left as protecting caps on solitary hills. Volcanic outbursts began in this region of Central France rather before the middle of Tertiary times. They were later than that in which the beds of our London Basin were deposited, for they began in some part of the period which used to be called Lower Miocene by geologists, but is now commonly termed Oligocene. When they finally ceased is not easily determined;

it was certainly after man had made his appearance in the region.[1] It is possible that isolated but enfeebled outbursts may have occurred even since the beginning of the Christian era. The question is one which has excited some controversy, but the facts lie in a comparatively small compass. Two ancient writers,[2] the one a bishop of Clermont-Ferrand, the other an archbishop of Vienne, not a generation later, use certain phrases which, if interpreted strictly, imply that there were volcanic outbursts in some part of Auvergne a few years (the exact date is not given) prior to A.D. 470. There were certainly earthquakes, and, in addition to that, we learn that the wild animals, in their terror at the doings of nature, lost their fear of man—a thing not uncommon in time of eruptions; and that "fires often blazing were heaping over the tottering crests of the mountain summits a piled-up mound of ashes." That earthquakes and other strange portents occurred about this epoch we ascertain from more than one contemporary authority; but the question is how the words, of which the above is a literal translation, are to be interpreted. It would be natural to take them as describing volcanic outbursts in some part of the hill country which is included in the diocese of Vienne, for to that and to the

[1] According to Professor M. Lévy, *Bull. Soc. Géol. Fr.*, Ser. iii., vol. xviii., p. 705, some of the craters "ont dû, au moins en partie, précéder immédiatement les époques historiques."

[2] Sidonius Apollinaris, bishop 471–489 A.D., and Alcimus Avitus, archbishop 490–523 A.D.

neighbourhood of Clermont-Ferrand the writer is referring; but no one as yet has succeeded in identifying the place, for which we should first look in the neighbourhood of Montbrison. Those who are incredulous as to the occurrence of eruptions in this region at so late a date interpret the most important phrase in the sense of disastrous fires in the city. The words would bear this meaning, but the rhetoric would be extravagant, even for an ecclesiastical writer of that date.[1] But whatever be the truth in regard to this matter, we can undoubtedly find in Auvergne craters as fresh as those in the Phlegræan Fields, and lava streams hardly more weatherworn than those on the slopes of Vesuvius.

We may commence our examination in the neighbourhood of Clermont-Ferrand—a classic district in the history of vulcanicity. There are few views more striking to the novice, more characteristic to the expert, than that which can be obtained from almost anywhere on the east of the city, when we turn and look in the opposite direction. Above a wide and richly cultivated river-plain the hills slope up with comparative steepness for some hundreds of feet.

[1] The exact words are, "ignes sæpe flammati caducas culminum cristas superjecto favillarum monte tumulabant," of which the one translation is, "piled a mound of ashes on the tottering mountain crests"; the other (practically), "heaped ashes high on the fallen roof-ridges." Either translation is justifiable, but it is singular to speak of piling the ashes on the fallen ridges of the roofs; and the whole sentence is rather a bombastic one to apply to a bad city fire, so that the former rendering is much the more natural. The words of the later writer are less definite, but they also appear to refer more probably to a phenomenon of nature.

They are interrupted by fairly large and deep valleys; they descend in abrupt banks and irregular slopes of varying outline, which suggest the presence of more than one kind of rock. That, on more careful inspection, soon becomes evident, even at a distance. In some places the boldly rounded curves hint at the outcrop of some fairly durable coarse-grained rock, in others the steeper slopes, the closer furrows, the soil gleaming pale, through herbage sometimes scanty, seem to tell of friable marls, or at most of soft, crumbly limestone. The slopes, we notice, often lead up to a steep though rather low scarp —generally a wall of dark rock—and the level aspect of several portions of the plateau itself cannot fail to catch the eye. Of this feature also we shall presently discover the explanation. But what rises beyond its edge most of all arrests our attention. The plateau supports a number of hills, peculiar both in grouping and in form. Instead of any signs of system or approach to union in ranges showing some kind of relation, they are scattered sporadically, large and small, now more closely now more widely apart. Besides this their outlines are peculiar. The highest, with one or two comparatively inconspicuous, is a rather rounded or at most moderately rugged mass, which attracts notice more by its isolation than by any very marked singularity in its outline. That, however, is not the case with the majority. With them the dominant form is a fairly uniform and often rather steep slope, terminating in a flat top, which sometimes is

slightly higher at one end than at the other. These hills a very little experience enables us to recognise as extinct craters. We are looking at part of the great volcanic region of Central France, the eastern edge of one of its most important districts. Its history is a complex one, which will be more readily understood if we describe a few localities of a representative character.

Not very far back from the edge of the plateau, and within five miles of the town of Clermont-Ferrand, is the Puy du Pariou, one of the largest of those peculiar hills already mentioned, which rises 3970 feet above sea-level, and about 800 feet from its immediate base. On the southern side the cone mounts steeply from the plateau, at an angle approaching thirty-five degrees. It is composed of a reddish cellular scoria, now clothed in most places with moorland plants and coarse grass. No streams or gulleys furrow the surface, for rain, owing to the composition of the cone, sinks quickly into the ground, and rivulets cannot form on its sides. It terminates in an edge, everywhere rather narrow, and in some places reduced to a few inches. The crater within is like a huge deep bowl, about a thousand feet in diameter and three hundred in depth. But for the herbage with which it is covered within and without, but for the cattle-tracks on its slopes, one might imagine an eruption had not long ceased, and watch for the rising steam. It is dead, like Monte Nuovo; but there are few signs to show that the date of its final struggle is so much

PLATE IX. THE GRAND SARCOUY.

Seen above the Puy des Goules and other crater cones in Auvergne from edge of Puy du Pariou.

more distant from our own time. If we descend by the opposite side we observe, as indeed we cannot fail to have done from the summit, that the structure of the Puy is not quite so simple as we have just described. On the northern side it is half enclosed by an older, wider, and much lower crater-ring, of which, however, now only a segment can be seen. This is composed of scoria, generally similar to the other. But that is not all. On the eastern side, apparently issuing at the base of the higher cone, we find a great and rugged sheet of lava, which we can trace by its characteristic outlines for a considerable distance in that direction, broadening to the northward and southward over the plateau.

Careful study leads to the following conclusions: That at first a low, wide crater was formed, like one of those in the Phlegræan Fields; that in this a huge flood of molten lava welled up until it burst an opening in the eastern side, where the thin edge of the stream can be seen in one or two places overlapping the broken ash-bank of the old crater; and lastly, after this great evacuation, the discharge of steam and abundant scoria continued around a smaller but more energetic vent than the old one, which built up the Puy du Pariou, and buried the southern side of the original crater-wall.

To this grand lava-flow we shall return later on. For the moment we quit the neighbourhood, merely remarking that there are other craters within a short distance of the Puy du Pariou, one of the most per-

fect bearing the name of the Nid de la Poule. This, however, as one might suppose, is on a distinctly smaller scale, for though the crater is almost as deep, it is much narrower, and the cone is comparatively inconspicuous. We pass on to a pair of craters, which lie to the south, about six miles away—the Puy de la Vache and Puy de la Solas. These twin craters, the latter of which is not much lower than the Puy du Pariou, have shared the same fate, and illustrate a stage in the history of that cone. Both are composed of a similar dull reddish scoria, and have steep external slopes. On reaching the top of the first-named we find ourselves at the edge of a large crater, with yet steeper walls, composed of the same materials, but for the most part lying loose at their maximum angle of repose, and here and there crusted or patched with irregular strips of ragged, slaggy lava. One marked difference, however, from the Puy du Pariou is at once noticed; the south-western wall of the crater is gone, and through the breach, as is seen at a glance, a great flood of lava, which forms the floor of the crater, has streamed out into the open country.[1] Those patches of more solid rock adhering to the walls of the crater are found, on closer inspection, to assume the most fantastic forms. Much of it seems like agglutinated scoria. Mr. Scrope thought it had been left by the lava when it welled up in the old crater, before the wall of this gave way, and thus indicated the "high-water mark" of the flood. But

[1] Compare Plate X., fig. 2. Fig. 1 shows a "cinder cone."

PLATE X.

(1) Small cone and crater, Iseletta, Las Palmas, Grand Canary.

(2) Cone breached by lava-flow, Las Palmas.

the patches are at very different levels, so I suggest the possibility of their being great splashes of lava, mixed with scoria, which may have been squirted up by small explosions while the stream was flowing.

The structure of the Puy de la Solas is generally similar, but its materials exhibit in parts a very distinct stratification, and in one place on the eastern wall is a rather conspicuous dyke or "slobber" of lava. The streams from the two craters unite after flowing for about half a mile from the portals, and seem to consist of similar material. That from the Puy de la Solas is, at the surface, a dull grey cellular lava, and scattered over it irregularly are heaps and ridges of loose blocks, occasionally reminding one of old moraines, very rough and rugged, though now the outlines are a little softened by the heather and scrub which have sprung up among them.

We may turn next to another cone in the same district, the Puy de Gravenoire, which rises a short distance above Royat, a thriving watering-place, famed for its mineral springs. This cone, partly from natural causes, partly in consequence of excavations to obtain the scoria for making mortar, is in a more dilapidated condition than those already noticed, and affords, locally, views of its internal structure. The upper portion consists of loose scoria—reddish, blackish, and yellowish grey—with interspersed bombs and occasional streamlets of lava, and perhaps dykes. Most of the material varies in size from that of a plum to a large apple, and sometimes even to a rather

small melon; but on the eastern and north-eastern flank the *débris* is very much smaller. This finer ash, among which bigger masses are occasionally dropped, is as perfectly stratified as if it had been deposited by water, though, of course, the layers have much the same general slope as the cone. From this we may infer that the wind during the eruption which formed this part of the cone blew from the west and south-west, thus carrying the finer stuff to the opposite side. Great variety in form could be noticed among the coarser materials. "Pulled bread" was the best simile which I could find for them. The pieces were twisted and curved in all sorts of ways; some being slaggy, some very pumiceous, with vesicles now rounded, now elongated by subsequent movements. One pit on the south-east of the mass exhibited, at the time of my visit, a good section of a lava streamlet. It was about eighteen yards wide and generally from fifteen to eighteen inches thick, but near the middle it swelled up into a kind of mound, where it became between three and four yards in thickness. At top and bottom this streamlet was very rough and scoriaceous, but the interior was slaggy, with elongated vesicles.

Cones in a yet more ruinous condition are plentiful enough in Auvergne, as well as in several other volcanic districts, in which the eruptive action began in more ancient times; but before we carry further our investigation of them it may be convenient, in order to complete our history of an extinct volcano, to examine a little more closely one of the large lava-flows

which we mentioned above. We may select the one which has issued from the base of the Puy du Pariou. The surface is so exceptionally rugged and bristling that it has been compared, as stated by Mr. Scrope, to "a river suddenly frozen over by the stoppage and union of immense fragments of drift ice." In many parts, especially at some distance from the place of emission, it certainly merits such a comparison, but its surface gets a little smoother as the source is approached. The lava is a dark grey in colour, scoriaceous towards the outside, and everywhere rather full of vesicles, which are commonly a little elongated. So far as I saw, it is fairly uniform in its character throughout. At the first glance it might be compared, in places where its surface still remains almost destitute of any vegetation, to a tract of ground from which a glacier has recently retreated, leaving a number of small, rather ill-defined moraines, which, however, we soon see cannot really be represented by those peculiar outlines. The course which this flow has followed is an interesting one. As described by Mr. Scrope, it started in a north-easterly direction; then it was diverted by an obstacle and by the general slope of the ground towards the south-east. Here its line of advance was affected by other eminences, the result being that it came at last to the heads of two small valleys running up from different quarters into the plateau, over which the lava hitherto had flowed. Down these it descended, and was thus separated into two branches. The right-hand one descended by a

glen into a steep and sinuous gorge, which ultimately opens out on to the river-plain of the Allier. This "it threaded exactly in the manner of a watery torrent, turning all the projecting rocks, dashing in cascades through the narrowest parts, and widening its current where the space permitted, till, on reaching the embrochure of the valley, in the great plain of the Limagne, it stopped so abruptly as almost to form a crag, which is about fifty feet high."[1] The left-hand branch followed a course generally similar, but shorter. In both cases the rivers which flow down these valleys, since they have not been large and strong enough to carve out a new glen in the mass of lava, find their way beneath it, and issue at the foot in copious springs.

A large lava stream which has flowed in a generally similar way from the east side of the Puy de Gravenoire, has been cut through in making a road, and affords an interesting section,[2] illustrating one mode in which such a mass may act on the beds beneath. The broad valley of the Allier was once occupied by a lake, which was filled up with marl-like deposits, and has been subsequently re-excavated.

Over a remnant of these marls, which are well stratified, and here and there have harder and more stony bands, the lava stream has flowed. On them it rests with so uneven a base that it rises and falls for some fifteen feet in about thirty yards. The lava has caught

[1] Scrope, *Volcanoes of Central France*, p. 64.

[2] It is near the village of Beaumont, about two and one half miles from Clermont-Ferrand.

up and carried along large fragments of the marl, and into that it sometimes thrusts little dykes or veins. The marls, which are generally cream-coloured, are burnt to a reddish tint to a distance of from a few inches to about a yard underneath the lava, and the beds in the upper part are more or less bent. The lava has a rough, slaggy crust, varying in thickness from one to seven inches, from which there is a rather quick passage to a compact rock, traversed by irregular curving joints. Here and there, however, a slaggy portion occurs in the heart of the mass. This catching up of fragments of the underlying strata is not by any means universal, for in another quarry at some distance away, but in the same lava stream, the latter at one part lies

FIG. 10. LAVA STREAM (LEFT WHITE) CATCHING UP MARL (DOTTED).
a, Scoria.

with a rather even base, on laminated marls, which are discoloured and slightly indurated for a depth of a foot or so, but not otherwise affected. Here the mass of lava is about thirty feet thick, the upper half being rudely columnar, the lower traversed by irregular joints wider apart than the surfaces of the column, while in the last two or three inches it passes to a slaggy condition. But at each end of the pit the lava, as in the former sections, becomes entangled with the marls, and here the columnar structure disappears and the jointing is altogether irregular.

A very interesting section in this neighbourhood illustrates a phase in the volcanic history of Auvergne which finds a parallel not infrequently in other regions. It proves that intervals sometimes elapse between epochs of volcanic activity long enough for great changes to be wrought by the ordinary meteoric forces in the aspect of the country. The cones stand as we have stated, the associated lava-flows begin their course at a considerable elevation, perhaps a thousand feet, above the lower part of the plain of the Allier, to which sometimes they descend through tortuous glens. But on examining the country we find ample evidence that volcanic action commenced in this region at a much earlier epoch. In proof of this a single section may suffice for the present. It may be found on the left bank of the glen, which has been followed by the southern branch of the lava flood from the Puy du Pariou. If from the surface of that lava we climb the steep slope of this glen we

find that a rough ascent over a coarse granite leads to the foot of a thick mass of basalt, which rises above us like a wall. The upper part is columnar, the lower is obviously less regular in structure. Leaving this for a moment, we discover on closer examination that usually this basalt rests upon the granite, but that as we proceed eastward we come at last to the section of which a rough sketch is annexed. Here

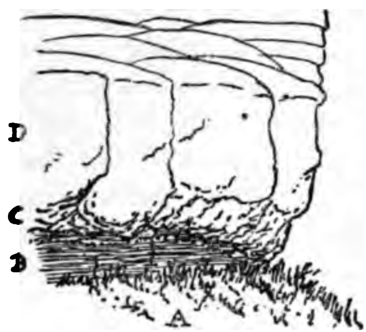


FIG. 11. BASE OF BASALT STREAM, AUVERGNE.
A, slope of Granite, partly grass-grown; B, Marl; C, slaggy Basalt; D, Basalt roughly jointed, passing into curved jointing, and that afterwards replaced by columnar.

the lacustrine marls already mentioned make their appearance, and gradually become thicker as they rest against the descending floor of granite, so that the basalt passes away from the latter to the former. This basalt, as we see when we have reached the summit of the mass, is the edge of a considerable sheet, now bearing the name of the Plateau de la Prudelle, which is a large fragment of an ancient lava-flow. Hence there can be no doubt that when this was emitted and flowed down the gentle slope of the

granitic plateau, the whole space now beneath it must have been filled up to this level with lacustrine marls, and these very probably were still beneath the surface of the lake. But at last that was drained, and in its bed the valley system, which we now see, began to be excavated. The marls were to a great extent washed away; the basalt-flows were furrowed and sometimes severed. As the valley of the Allier approached its present form the lateral stream cut down through basalt and marl into the granite below, forming large glens, which were overlooked by the remnants of the old lava-flows as by the walls of a fortress. When these glens, with the main valley, had been carved almost into their present shapes and levels a new phase of volcanic activity commenced. Cones again were thrown up and lava-flows were ejected on the upland, and the latter in some places poured down into the glens and streamed out upon the plains. In one or two cases the vents were actually opened in the beds of the valleys which had been excavated in the earlier lava-flows and the subjacent lacustrine rocks. This one example may suffice, but there are many others to be found in Auvergne, all telling the same tale. For instance, the historic hill of Gergovia, where the old ramparts of rough stone can still be traced, as on a hill fort in Wales, owes its strength to the fact that it is an isolated fragment of one of these ancient basalt-flows. From the base of its crags—themselves a formidable wall—the lacustrine marls slope down to the plain below like a long and

steep glacis. So great indeed is the natural strength of the fortress that in it Vercingetorix was able to repel the attacks of the army of Cæsar.

Partially ruined cones occur both in Auvergne and in the Eifel. In the latter region craters are perhaps less frequent than in the former, but cones of scoria, indicative of a ruined "puy,"[1] are common enough, and often the more conspicuous because they occur scattered sporadically over a district consisting of sedimentary rocks. Pits are frequently opened in these cinder heaps, for the material is useful for various purposes, and this enables us to see the structure. They exhibit a rude stratification of coarser and finer materials, but not infrequently larger bombs occur irregularly, where they have dropped like cannon-balls among rifle-bullets, while here and there we may mark the course of a driblet of lava.

Yet in many of these the structure and character of the materials clearly reveal the history of the hill. Excellent sections are often exposed to view. The whole mass, so far as can be seen, is composed of fragmental materials, varying from fine dust to blocks which may be three or four cubic feet at least in volume. These exhibit a more or less distinct stratification, and are arranged roughly in beds, the dip of which corresponds generally with the external slope of the hill. In some cases the materials, especially those of finer grain, exhibit the phenomenon known

[1] This term is now commonly extended to denote rather small cones, such as those described above in Auvergne. (See Plates IX. and X.)

to geologists as false-bedding, for the diverse strength of the explosions and the action of the wind during a volcanic eruption produce effects similar to that of a river current of variable velocity.

But a description of a single instance may serve to give a general idea of dozens of ruined cones in Auvergne and the Eifel and other volcanic regions, so I select a quarry of considerable size in the lower part of a volcanic hill rising from the Brohlthal in the second district. The surface soil, less than a foot thick, passed into a rather dark scoria composed of fragments which for the most part were about the size of a hazel-nut. The absence of larger pieces and of any appreciable quantity of dust gave a generally uniform aspect to this bed, which was about four feet in thickness, and followed the slope of the hill. On the lower side it changed rapidly into another bed, composed generally of much finer materials, but with little sloping streaks of distinctly coarse scoria, and here and there a block or "bomb," which might be even a foot in length. This band, which was a few inches thinner than the former one, also conformed, as did its coarser streaks, to the general slope of the hill. Beneath it came a mass of coarser and more heterogeneous materials, in which a pit had been opened for a depth of four or five yards. This mass, as might be expected, was less definitely stratified, though here and there one could see, from the position of the larger blocks or from occasional layers, that it, too, had been deposited on a slope. The fragments in it generally

ranged from about the size of a man's head down to quite small bits, sometimes even less than peas. But the majority of the pieces would probably vary from the size of a hazel-nut to that of an apple. A fair number, however, of bigger blocks were included in this mass of scoria. Some of them, a couple of feet or more in diameter, were certainly only fragments of larger size from the crust of the lava ejected with the scoria, but now and again came streaky masses of somewhat cellular lava, becoming more compact towards the interior, which were very irregular in outline, both top and bottom, and attained to a length of a few feet, seldom exceeding a dozen inches in thickness. Their peculiar form made it rather improbable that these masses were actual bombs, though, of course, they have been ejected from the crater. Two explanations are possible: either that here and there the molten material has bubbled above the rim of the crater, as when a pot boils over, and has run in a narrow streamlet down the slope, or that some of the liquid material has been squirted explosively into the air, and when it fell on the outer part of the cone was still sufficiently fluid to run down it for a time.

To ascertain the former physical geography of the mass when in a more advanced stage of ruin is sometimes a difficult task, demanding long and careful work, every detail in which cannot always be settled. Such, for instance, is afforded by Mont Dore, a volcanic group, which in its day was much larger than Vesuvius, and must have risen when perfect to a far

greater elevation.[1] The culminating point of this volcanic mass, the Puy de Sancy, at the present time is 6184 feet above sea-level. It is the most elevated spot in Auvergne, indeed in the whole of France west of the Alps, and it commands, as might be expected, a magnificent view over this singular region of ancient volcanoes. The base of the *massif*—a rude ellipse in outline—measures about twenty miles from north to south, and rather more than fifteen from east to west. It rests, like so many of these volcanic hills, upon an elevated foundation, composed of granite and other crystalline rocks, which probably are connected with the earliest geological formations of which we have any knowledge. The eruptions which built up this huge pile commenced, according to Professor Michel Lévy,[2] in all probability in the Lower Pliocene; they were certainly in full activity through the Middle Pliocene; they continued through the Upper division[3] of that period, and had not wholly ceased, though the outbursts then were sporadic and away from the centre, in the Quarternary; but from the highest point every trace of a crater has disappeared. It does not even consist of indurated scoria, but is the top of a mass of trachyte, the highest of a group of ridges which descend in steep crags on their

[1] The total height of Vesuvius in its present condition is about 4000 feet, and the diameter of its base nearly eight miles.

[2] *Bull. Soc. Géol. de France*, Ser. iii., vol. xviii., p. 775.

[3] Using the divisions adopted in the French map, the Middle Pliocene being characterized by *Mastodon arvernensis* (among others) and the Upper by *Elephas meridionalis*.

western and south-western sides. The *massif*, as shown in Professor Lévy's sections, is formed by a series of lavas and beds of volcanic ash ejected from more than one centre, and most probably at different times; for the materials exhibit considerable diversity. The earlier discharges appear to have been ashes of an acid rock, in which, however, are small flows of rather variable character, one extreme being represented by a kind of obsidian, the other by a phonolite.[1] Flows of basalt, seemingly rather local, may have followed; but of these the age is not easily fixed, and they may possibly be even older than the preceding. Certainly later than both is another mass of acid ashes, occasionally containing fragments of considerable size and generally of a light colour. In these also lava-flows occur, which, as before, differ considerably in composition, varying from rather basic basalts to andesites. To this mass the greater part of the mountain belongs. Yet newer is a group of lava-flows, consisting of more acid andesites and of trachytes, containing large crystals of sanidine.[2] This is succeeded by another group of andesites, differing somewhat in mineral character, followed by phonolites, which are found both in flows and in intrusive masses, as at the Roche Sanadoire and Roche Tuilière. These are followed by a number of basalt-flows, which appear to correspond in age with those forming the

[1] A rock allied to the trachytes, but containing the mineral nepheline.

[2] From these the summit of the Pic is sculptured. Some of them much resemble the well-known rock of the Drachenfels on the Rhine. Sanidine is a variety of orthoclase felspar.

plateaux in other parts of Auvergne. Finally comes another group of flows—also of some variety of basalt—which seem distinctly to belong to a later age, and are associated with partially preserved craters. This succession can only be made out by long and careful study of the mountain as a whole, but that it is built up by successive discharges of lava and of ashes, and that these exhibit considerable variation in mineral character may be ascertained without going any great distance from the little town of Mont Dore, the mineral springs of which have been noted since the days when Gaul was a Roman province.

The Puy de Dôme itself, the highest summit in the neighbourhood of Clermont-Ferrand, and the centre of so many associations, both historic and scientific, retains no trace of a crater. This, however, is not of itself a proof of the great antiquity of the mass, for we cannot be certain that it ever possessed one. According to Professor M. Lévy the central part of the Puy de Dôme probably consists of a dyke-like mass of a peculiar variety of andesite.[1] The puys composed of this material have a peculiar outline, and generally appear not to have undergone much erosion, though they have suffered to a certain extent. The most remarkable of all is the Grand Sarcouy,[2] about 3700 feet in height, the shape of which might be compared to a pudding made in a rather shallow basin. On its flattened summit frag-

[1] It is compact, pale grey in colour, and distinctly decomposed.

[2] Plate IX. It is about 3½ miles nearly to N.N.E. of the Puy de Dôme.

ments of scoria are strewn, but these are only the hailstones which have fallen during an eruption from some neighbouring crater. The mountain itself seems to consist entirely of a mass of rather rotten, fine-grained andesite, generally similar to that of the Puy de Dôme. The outline presents some resemblance to those curious intrusive masses of igneous rock to which the name laccolite has been assigned. These, supposing them to have issued from a single orifice, might be compared to a full-grown mushroom in shape. It was suggested by Mr. Scrope, and his idea seems generally adopted, that the Grand Sarcouy and its kindred are in reality more nearly related to a lava-flow than to an ordinary volcanic cone; in other words, that they mark non-explosive eruptions of a lava stream which issued from the ground at a comparatively low temperature, and thus in a very pasty condition. If any scoria was ejected it was only at the first opening of the vent, and this would be immediately buried by the great mass of lava which welled up slowly from below (as when oil-paint is squeezed out of its tube) and formed a great mound above and around the vent, since it was too viscous to flow as a stream.

In the view from the summit of the Puy de Sancy one or two rounded spots of blue water may be seen glittering in the sun, which are enclosed by a bank closely resembling the ring of a crater. These are small examples of a variety of the extinct volcano called a crater-lake, which may be conveniently ex-

amined at this juncture, but of which more numerous and larger examples can be found in other countries, as for instance in the Eifel.

There, half a league from Daun, is a group of three crater-lakes. The smallest and nearest to the village is called the Gemünder Maar. It lies among low hills, 1325 feet above sea-level, a basin of blue water only eighteen acres in extent, or rather less than 350 yards in diameter, and 200 feet in greatest depth, at the bottom of a bowl-like hollow, the sides of which are partly cultivated, partly covered with trees. The lip of the crater is rather irregular. Its eastern side rises in a " hogsback " hill—the Mäuseberg—1845 feet above sea-level, while it is notched by more or less conspicuous openings in other parts of the ring. The slopes—mostly rather steep—are generally wooded; round the water is a zone of shelving cultivated land. Bombs and bits of scoria are scattered about, but most of the rock which crops out in the crater is of sedimentary origin—more or less of a slate. It is only in the north-east slope that an accumulation of scoria can be seen, and even this, so far as one can judge, is not many feet in thickness. Within a short distance on the opposite side of the Mäuseberg lies the Weinfelder Maar, which is rather more elevated, for it is 1570 feet above sea-level, and is forty acres in extent, but its depth—220 feet—is nearly the same. Some masses of hard volcanic sand and pumice, as well as of a nearly vertical shale or slate, crop out on the sides of the crater, which is much more shallow than

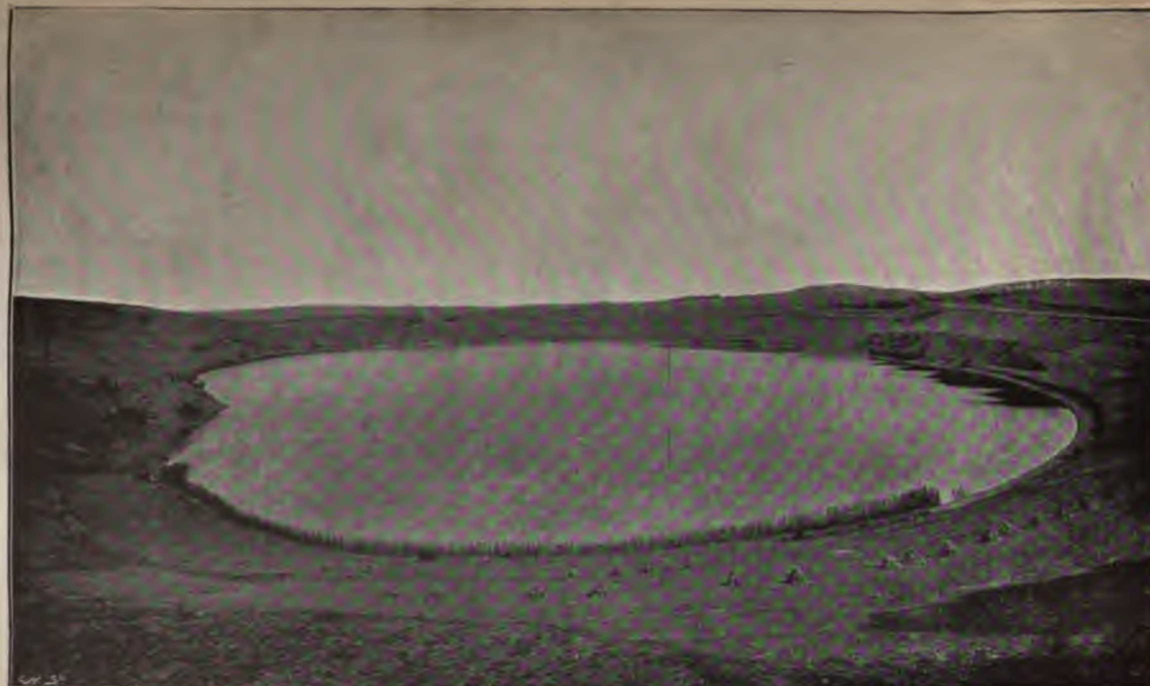


PLATE XI. A CRATER-LAKE. THE WEINFELDER MAAR.

the former one. The inner slopes are barren, and, though no less distinctly a crater, it is not so impressive as the Gemünder Maar. The third crater-lake—the Schalkenmehrer Maar—is only sixty feet above the level of the Gemünder Maar, but it is the largest of all, for its area is fifty-five acres. It is the least picturesque of the three, because the walls are low and occupied by cultivated fields. Here apparently there are twin craters, merely separated by a low bank, in plan something like a figure of 8, one of them being the present lake, which at most is only 105 feet deep; the other is now only a marsh, from which a streamlet runs. Here also volcanic materials are by no means conspicuous, and slate is exposed in a ravine. Some miles away is the Pulver Maar, a larger crater than these, for it is ninety acres in area and 300 feet deep. This is more distinctly volcanic in its surroundings, though it rises but little above the upland. Its sides, as in the other cases, are often masked by cultivation and copses, but they exhibit in occasional sections inclined strata of volcanic sand and fine scoria. Still, even here, a slaty rock is visible in one part of the crater. Larger than any of the others in the Eifel is the well-known Laacher See, for it is about a mile and two thirds in diameter. This, however, is shallower than most of them, for the greatest depth is not more than 175 feet; it is also lower, for the surface is only 900 feet above sea-level. It lies in a boat-like hollow surrounded by low hills, with a narrow depression or pass on the northern side com-

municating with the Brohlthal, and a broader opening on the southern or south-western side. Here, though the slaty foundation rock of the country evidently is not far away, for it can be easily discovered, volcanic materials are abundant, and the crags, which are half concealed by the woods on the inner slopes of the crater, consist of rudely stratified ash and scoria, with occasional outcrops of dark-grey lava.[1]

Italy possesses several of these crater-lakes, two of the most noted being among the Alban hills. This mass, wholly volcanic, culminates in Monte Cavo, a cone and crater the lip of which is at a height of 3130 feet. The Alban lake is the larger, being an oval in form about 2½ miles long and 1½ miles wide. Its surface is only 961 feet above sea-level, but the depth is stated to be 530 feet; moreover, as is well known, the water formerly stood at a higher level. The still more beautiful and smaller[2] Lago di Nemi is about 100 feet more elevated. Its waters lie beneath steep, craggy, and wooded slopes, which rise above them to a height of over 300 feet, and its depth is about the same. We may remark in passing that these lakes, with two other craters now dry, appear to have obliterated the outline of a very ancient crater more than six miles in diameter, in the middle of which Monte Cavo towers up like, but much higher than, the cone of Vesuvius in the enclosure of Monte Somma.

[1] The great lava-flow, in which are the quarries of Niedermendig (worked since Roman times), is on the south-west side of the crater of Laach, but how far the two are connected is uncertain.

[2] Its larger diameter is rather more than a mile.

But the Lago di Bolsena is the most remarkable of the crater-lakes in the region of Central Italy, for it is about 28 miles in circumference, and its larger diameter is 10¼ miles. It lies among volcanic hills, which rise generally from 300 to 500 feet above its surface, though some points in this ancient crater-ring are still more elevated—one, Montefiascone, on the south-east side, being nearly a thousand feet above the lake,[1] which itself is 962 feet above the sea. The volcanic mass rises gradually from the plain. Like the Lago di Bracciano, another important crater-lake[2] some miles nearer Rome, this crater is cut through by a river valley, which in each case has had the effect of lowering the waters of the lake. Its surface is interrupted by two small islands, the structure of which shows them to be cinder cones, marking the site of sporadic outbreaks.

One more example of these volcanic basins filled with water may be given, and in this case from the New World. Crater Lake, in Oregon,[3] lies on the summit of the Cascade range, about half-way between the extinct volcanoes of Mount Shasta and Mount Hood. That range in this neighbourhood forms a broad platform surmounted by numerous extinct cones. Crater Lake itself is approximately circular

[1] That, however, is a later eruption on the edge of the old crater-ring. See Professor Judd's account, *Geol. Mag.* (1875), p. 351.

[2] It is nearly circular in form and about 6¼ miles in diameter.

[3] For description see J. S. Diller, *Amer. Jour. Sci.* (1897), p. 165. A map with descriptive text and illustrations has been published by the U. S. Geological Survey, for the use of a copy of which I am indebted to Sir A. Geikie.

in outline, its basin having at the top an average diameter of a little more than five and a half miles. From the rim a gentle slope, clothed with forest, but still practically uninjured by denudation, descends to the surrounding platform, but the walls of the crater are precipitous. The actual crest of the cone is anything but level. At the western side it attains to a height of about 8200 feet above sea-level, but on the eastern not more than 6750 feet. Here it is only about 500 feet above the surface of the lake. Over a large area the depth of the water is about 2000 feet, but it shallows towards the western end of the basin, where a volcanic mass, named Wizard Island, rises above the surface. The upper part of this is a cone of reddish lapilli, with a crater at the top about 150 feet in depth, but the lower part is composed of lava, and the whole mass rises about 2500 feet above the more level portions of the lake floor. Here, then, as at the Lago di Bolsena, a vent of limited size must have been opened after the formation of the great crater, and near its western end, by the ejections from which Wizard Island has been formed. When the walls of the main crater are studied, the beds of scoria and lava of which they are composed are seen to slope away from the centre of the lake, and to indicate that they are the remnants of a larger and loftier cone, which was built up by successive discharges from a vent situated in that quarter. Indeed, the diameter of Crater Lake in its present condition is about the same as that of Mount Shasta at an ele-

vation of 8000 feet. Hence its cone may once have risen high above the present level of the rim, though probably not so much as 5000 feet,[1] and the part removed may have been at its base nearly six miles in diameter. But how was it destroyed? Was it sent flying up into the air, like the half of the crater-wall of Somma, or by a series of engulfments, associated no doubt with explosions which shattered the foundations? This question has been discussed by Mr. Diller and Major Dutton, and both adopt the latter explanation. They urge that if the cone had been blown up we ought to find the materials forming a ring commensurate with the lake. Now there is undoubtedly pumice scattered over the surface of the platform for many miles round the lake, but it is not sufficiently abundant or arranged in such a manner as to resemble the results of explosions on so grand a scale. It may well be the fruits either of one of the eruptions which built up the main cone, or even of that later outbreak which gave rise to Wizard Island. But if the crater had been undermined by the escape of a mass of liquid lava, as we have described in one of the eruptions of Kilauea,[2] from some outlet at a lower level, aided by a succession of minor explosions to shatter the walls, then we should expect to find the rim comparatively narrow and the remaining mass composed of imbricated and overlapping

[1] The height of Mount Shasta is 14,350 feet, but as the outer slope of Crater Lake is not nearly so steep, the destroyed cone probably did not attain the same elevation.

[2] See page 29.

sheets of lava and of fragmental materials; and that is precisely the structure which is disclosed by a study of the sections in the precipices which surround Crater Lake. This explanation is preferred by Major Dutton, who believes that the present wide and low crater of Kilauea has had a similar origin; and though no doubt some basins are the basal wrecks of great cones, yet the other mode of enlargement is no less possible, and in certain cases seems even the more probable. The water in Crater Lake, as is usual with these basins, has no visible outlet, but as it seems to maintain the same level there must be some way of escape, for it is not probable that evaporation would just balance precipitation. We need not, however, assume the existence of any fissure or funnel. Percolation through the beds of scoria, of which the truncated cone is largely composed, would quite suffice to account for the disappearance, and very likely the water may break out as springs elsewhere in the Cascade range, as happens in some of the limestone districts of the Alps, where the rain which falls on the surface is entirely swallowed up. Materials so extremely porous as the more pumiceous kinds of scoria and ashes must offer little resistance to the passage of water, and would be very slow in becoming saturated, even in the absence of springs. In fact, in the case of the majority of craters, precipitation is obviously more than counterbalanced by evaporation and absorption, because, as a rule, the bottom of the bowl is dry.

These crater-lakes suggest two questions: How

are their waters retained, and to what cause are they due? It has been stated that in many cases the scoria cones in Auvergne so quickly absorb the rain that it seems to have no erosive effect. Why, then, as these crater-lakes must now be fed wholly by rain-water, does it not disappear by percolation into the earth? If the floor of the crater were formed of lava, as would be the case were Kilauea to become extinct, water might easily be retained. Still, even in this case, unless the walls also were of lava, which does not appear to be the case with the above-named lakes, the water might escape through them. This might happen at first, but the scoria after a time would probably solidify,[1] and by becoming less permeable would check the leakage. All the cases which have been mentioned above are a little exceptional in their mode of occurrence. Some of those in the Eifel can hardly be called cinder craters, for they are rather holes blown out from the slaty rocks of the country; while all the others are at no very great elevation above sea-level, and are surrounded by a great mass of materials. The occurrence of a lake in a volcanic crater of the ordinary form, such for instance as in Monte Cavo itself, if not unknown is certainly a very great rarity. In such, apparently, only snow can accumulate.

In regard to the second question, the areas of these

[1] In the case of the Central Italian and some of the Eifel crater-lakes, the fact that the lavas are leucitic may be of some significance, for tuffs of this nature seem to "set" well in the presence of water.

craters are large in proportion to their height. It is difficult to suppose them to have been formed, like the ordinary crater-cones, by the piling up of materials round an orifice of comparatively small size. In such as those near Daun there is no great quantity of ash and scoria; they look as if a piece of the earth's crust had been blown away and a hole had thus been made. That is most probably the case. The same explanation may be applied, though with a difference, to the crater-lakes of larger area which are surrounded, like those in Central Italy, with greater quantities of volcanic material. Here probably the upper and major part of an important volcano has been actually destroyed. The catastrophe of Somma in the Plinian eruption, of Kobandai-san, of Papandayang,[1] has been repeated on a yet grander scale. It may have been brought about in this way. On a foundation, measuring some miles at least in diameter, a volcanic group—probably from several orifices—has been built up, one of which ultimately may have mastered the others and risen on high as a central cone. This, at last, has become clogged, but before the incandescent masses below have materially cooled. Thus vast quantities of vapour have accumulated behind the obstruction—the volcano is in the condition of a boiler with its safety-valve fastened down. At last it bursts. The central portion of the mountain is sent flying into the air, perhaps by one

[1] In this case the gulf left after the explosion is said to have been fifteen miles long and six broad.—Judd, *Geol. Mag.* (1875), p. 353.

great explosion, as at Kobandai-san, perhaps by a number of them in quick succession, as seems to have been the case at Krakatoa; only the lower part of the mountain is left, the "basal ring" of a wrecked volcano[1] forming a wall of circumvallation round the newly opened cavity or crater. The explosions in some cases, as happened at Somma, and probably on the flank of Monte Cavo, produce unsymmetrical results. A portion only of an old crater may be destroyed, a piece may be blown out of the side of a mountain, or nothing more than an interrupted line of huge fragments, instead of a continuous wall, may remain as memorials of the destroyed volcano. These "basal wrecks" often can be detected on the careful study of a district. For instance, a great ring-shaped crater-wall can be traced around Monte Cavo, though about a third of it has been obliterated by later outbursts, which, however, probably preceded the formation of the lakes. Krakatoa itself, where a performance of this kind was exhibited in 1883, appears to be situated on the basal ring of a much larger volcanic mass. The circumference of this

[1] Some thirty years ago I unwittingly performed an illustrative experiment. I had taken a share of a cask of a light wine imported by a friend from the south of France. It was supposed to be only very slightly effervescent, and so was put in bottles of ordinary strength. On visiting my cellar about a fortnight after the wine had been laid down I found the bottles were beginning to burst, and before I could use or give away the wine nearly a dozen were lost. In one case, where the cork had been badly secured, it was ejected, in others a piece was blown out of the shoulder, in others again the neck was blown off. The first illustrates what happens in an ordinary eruption after a period of quiescence, the second and third show the two modes of "wrecking" a volcano described above.

mountain is stated[1] to have been, at the present sea-level, about twenty-five miles, and in height it very probably more than equalled Etna.

But a still clearer instance, though not on so large a scale, is afforded by the islands of Santorin in the Greek Archipelago.[2] Here volcanic outbursts are known to have occurred at intervals during quite two thousand years. Thera, the largest of the islands, is crescent-shaped, with a markedly irregular inner border, the two horns pointing to the west. Separated from the northern one, and in the line of the curve afforded by the opposite part of Thera, is the island of Therasia, divided from the former by a channel about two and a half miles across. A gap more than double this width separates Therasia from the southern horn of Thera, which, however, is interrupted by the small island of Aspronisi, and the soundings in it are generally shallow. These islands accordingly indicate the basal wreck of a volcanic mountain, the dimensions of which, at the present sea-level, must have been about ten miles by eight miles.[3] But the sea within this enclosure is interrupted by a group of small islands, two of them, not very different in size, being considerably larger than

[1] *Report of Krakatoa Committee of Roy. Soc.*, p. 6.

[2] Described very fully by Sir C. Lyell, *Principles of Geology*, chap. xxvii.

[3] The remnants consist of volcanic materials with the exception of Mount St. Elias (1887 feet), in the southern part of Thera, which is composed of granular limestone and argillaceous schists, though it is nearly thrice the height reached by any volcanic rock. This fact seems to indicate a rather complete destruction of the original volcano.

e third. They are arranged in a linear direction, ıd rise from rather deep water. Of these the hist-ry is fairly well known. Two hundred years prior › the Christian era only the outer ring seems to have een in existence, and as to when or how it was ›rmed tradition is silent. But in the year 186 B.C. he southernmost of the three islands, now called)ld Kaimeni, or, more strictly speaking, a portion of t, then named Hiera,[1] was thrown up. In 19 A.D. nother island appeared, rather more than a furlong way, which was named Theia.[2] The two were soon nited by subsequent eruptions, and additions to Old Kaimeni were made in the years 726 and 1427. An ruption from a different centre almost half a league way produced, in 1573, the cone and crater called Aicra-Kaimeni.[3] Lastly, in 1707 and 1709, a third sland, called Nea Kaimeni,[4] was thrown up, a differ-nt kind of rock being ejected on each occasion. Eruptions, indeed, did not cease till three years after he latter date, and the final result was a cone with a rater about eighty yards wide, the summit of which was 330 feet above the sea.[5] Besides this, two monti-cules have been detected by soundings in the neigh-bourhood of the Kaimenis; and, in 1650, a submarine eruption occurred about three and a half miles to the north-east of Thera, which is now marked by a shoal

[1] Holy Isle.
[2] Divine Isle.
[3] Little Burnt Island.
[4] New Burnt Island.
[5] A sharp eruption occurred in 1866 from two vents at Nea Kaimeni—by one a lateral cone was thrown up to a height of about 200 feet; by the other, which broke out under water, an addition was ultimately made to the island.

ten fathoms beneath the surface at the shallowest parts.

The following extract from Sir C. Lyell's classic work gives an excellent description of the real outlines of this half-submerged volcanic group. After remarking that Thera, "which constitutes alone more than two thirds of the outer circuit," presents everywhere on the inner side high and steep precipices composed of volcanic rocks, and that we may compare the inner islands, notwithstanding their linear grouping, to the cone of Vesuvius, and the outer islands to the broken crater-ring of Somma, he states[1] that if the water were drained away "a bowl-shaped cavity would appear, with walls 2449 feet high in some places, and even on the south-west side, where it is lowest, nowhere less than 1200 feet high; while the Kaimenis would be seen to form in the centre a huge mountain five and a half miles in circumference at the base, with three principal summits (the Old, the New, and the Little Burnt Islands) rising severally to the heights of 1251, 1629, and 1158 feet above the bottom of the abyss. The rim of the great cauldron thus exposed would be observed to be in all parts perfect and unbroken except at one point, where there is a long and deep chasm or channel, known by mariners as the 'northern entrance,' between Thera and Therasia, and called by Lieutenant Leycester the door into the crater. It is no less than 1170 feet deep." More than one explanation, he

[1] *Ut supra*, vol. ii., p. 71, eleventh edition.

says, may be offered of the last-named feature. It may be the remnant of a deep valley of subaerial erosion, formed at a time when the whole mass was more elevated by at least twelve hundred feet than it is at the present day, or (as I should think more probable) it may mark a rent of exceptional depth made during the destruction of the ancient volcanic cone. That there has been also a subsidence is by no means improbable, for it is not unusually a consequence of very violent eruptive action, and the low dip of the successive deposits (which slope away from the centre) in the three islands of the outer ring accords with this view; but it may be doubted whether subsidence alone is adequate to explain the phenomenon as a whole. Be this, however, as it may, Thera, Therasia, and Aspronisi are generally admitted to be remnants of the basal wreck of a very large and ancient volcanic mountain.

Other instances could easily be added, but it may suffice to quote one which exhibits a similar action, though in a slightly different way. This is the singular amphitheatre in the flank of Etna, called the Val del Bove, which also has been described by Sir C. Lyell,[1] who attributes it to the effects of a great explosion. It is, to quote his words, "a vast amphitheatre, four or five miles in diameter, surrounded by nearly vertical precipices, the loftiest being at the upper or eastern [western ?] end, where . . . they are between 3000 and 4000 feet high, and the others

[1] *Loc. cit.*, chap. xxvi.

on the north and south side diminishing gradually from that height to 500 feet as they extend eastward. The feature which first strikes the geologist as distinguishing the boundary cliffs of this valley is the prodigious number of vertical dykes, which are seen in all directions traversing the volcanic beds. The circular form of the great chasm, and the occurrence of so many dykes, amounting perhaps to several thousands in number, cannot fail to recall to the mind of everyone familiar with Vesuvius the phenomena of the Atrio del Cavallo, although the Val del Bove is on a scale as far exceeding that of Somma as Etna surpasses Vesuvius in magnitude." Sir Charles Lyell calls attention to the fact that certain appearances, abnormal at first sight, lead to the conclusion that on part of the site of the Val del Bove an independent centre of eruption formerly existed, about half a league to the south-east of Mongibello, the present central cone. The latter is supposed ultimately to have become the principal channel of discharge, burying the other one,[1] which was thus effectually sealed up. But the imprisoned vapours, which still sought escape in this direction, were at last powerful enough to cause an explosion, which sent a vast piece of the mountain flying in fragments through the air.[2] The conditions, however, which were then in existence, did not lead to the construction of a lava cone

[1] This he distinguishes by the name of Trifoglietto.

[2] In this case, to return to our former comparison, a piece was blown out of the shoulder of the bottle.

around the reopened vent, though on the floor of the Val del Bove some small cones have formed, which still discharge steam. But sometimes engulfment may produce a basal wreck.

Before proceeding further in the study of natural dissections of a volcanic mountain we may pause to examine one rather abnormal form of eruption, traces of which may be occasionally recognised. Fissure eruptions, as discharges of this kind are called, are characterised by the general absence of cones, at least of any importance, and by the large area which is covered by the lava-flows. One of the most notable instances, at least of comparatively modern date, is to be found in Western North America. "The extent of country which has been flooded with basalt in Oregon, Washington, California, Idaho, and Montana . . . has been estimated to cover a larger area than France and Great Britain combined, with a thickness averaging 2000, but reaching in places to 3700 feet. The Snake River plain in Idaho forms part of this lava flood. Surrounded on the north and east by lofty mountains, it stretches westward as an apparently boundless desert of sand and bare sheets of black basalt. A few streams, descending into the plains from the hills, are soon swallowed up and lost." Sir A. Geikie[1] gives the following graphic description of the scene: "There were no visible cones or rents from which these floods

[1] *Geological Sketches*, p. 271. The preceding passage is quoted from his lucid summary of the work of the American geologists.—*Text-book of Geology*, book iii., part i., section ii.

[redacted]

of basalt could have proceeded. We rode for hours by the margin of a vast plain of basalt, stretching southward and westward as far as the eye could reach. It seemed as if the plain had been once a great lake, or sea, of molten rock, which surged along the base of the hills, entering every valley, and leaving there a solid floor of bare black stone. We encamped on this basalt plain near some springs of clear cold water, which rise close to its edge. Wandering over the bare hummocks of rocks, on many of which not a vestige of vegetation had yet taken root, I realised with vividness the truth of an assertion, made first by Richthofen, but very generally neglected by geologists, that our modern volcanoes, such as Vesuvius or Etna, present us with by no means the grandest type of volcanic action, but rather belong to a time of failing activity. There have been periods of tremendous volcanic energy when, instead of escaping from a local vent, like a Vesuvian cone, the lava has found its way to the surface by innumerable fissures opened for it in the solid crust of the globe over thousands of square miles. I felt that the structure of this and the other volcanic plains of the far West furnish the true key to the history of the basaltic plateaux of Ireland and Scotland,[1] which had been an enigma to me for many years."

[1] The basalt plateaux of Abyssinia and the "Deccan traps" of India are most probably other instances of fissure eruptions. In the latter, according to Medlicott and Blanford (*Geol. India*, chap. xiii.), the vast sheets are persistently horizontal, the rocks below are riven by dykes, and there are no volcanic cones.

The lava floods of the last-named districts, in some places, certainly cannot easily be explained in the ordinary way as streams from rifts on the flanks of a central cone, and, besides this, the underlying sedimentary rocks offer testimony which is favourable to the above-mentioned interpretation. No better instance can be found than at the headland of Strathaird, which was described and drawn by John MacCulloch nearly eighty years ago. The well-bedded calcareous sandstones of Jurassic age, exposed in a wall-like cliff rising from the sea, are riven again and again by dykes, generally vertical, but sometimes inclined, and occasionally only a few yards apart, while in the rear lies the remnant of a great sheet of basalt, which has been poured out from these fissures. In this part of Skye the basalt has yielded more readily to the action of the sea and the atmosphere than the indurated stratified rock, so that the latter projects in masses, like huge buttresses or bastions from the wall of a castle. The regularity of this structure leads us to suspect that the rock was already jointed when the liquid lava approached this spot on its upward journey.

The circumstances to which this peculiar type of eruption is due are not easily understood. It seems to require the presence, at no very great distance from the surface, of a pool-like reservoir of lava, which, under the pressure of fresh supplies from below, gradually uplifted the overlying stratum till the latter broke up under the strain into more or less

rectangular masses determined by the pre-existent joint-planes, and then the lava welled up through the fissures until all the ground above was flooded. The Isle of Skye, as every geologist knows, is remarkable for the frequency and regularity of its basaltic "sills," which, in some places, are intercalated among the sedimentary deposits with such uniformity as to deceive even very experienced observers, who have ascribed them to contemporaneous eruptions; that is, to the Secondary instead of to the Tertiary

FIG. 12. HEADLAND, STRATHAIRD.

era. At the outset a widely extended mass of molten rock must have been in existence at a very considerable depth from the surface; because, as we shall hereafter see, we cannot suppose that the igneous rock would be made by the melting-down *in situ* of sedimentary deposits. The molten material underwent pressure, and thus escaped in the direction of least resistance. In many cases this would be upward. At first, in all probability, the

fissures would be few and far between, but of a considerable size. After a time an exceptional want of cohesion between two beds might afford the lava an easier passage in a horizontal than in a vertical direction; thus another lake-like mass might be formed, but this time comparatively shallow. Its volume also would be gradually increased by accessions from the reservoir below, until at last, not seldom because it encountered some more obstructive rock-mass, it began to lift the overlying strata. These in some cases would be rent only by one or two great fissures, but in others they might be ruptured in the way already described, and then the lava might well over upon the surface as water flows from the bottom of a boat when its seams are leaky.

Returning now to the study of dissected volcanoes, we find, as already stated, some instances in such districts as Auvergne. Perhaps the most notable of those illustrative of the stage which we are about to describe—that where the crater has vanished and the cone has become a shapeless ruin—is to be found at Le Puy-en-Velay. Nature and art have co-operated in enhancing the picturesqueness of this ancient town. It climbs the slopes of a bold hill which rises abruptly from the bed of a valley. On the southern side the ancient cathedral projects far above the roofs; on the northern, a bare pinnacle of rock towers up, crowned by an old chapel; the central mass culminates in a craggy block, now adorned by a huge statue of the

Virgin, which could well be spared. The general effect, however, is most striking. That central mass and that pinnacle, almost a natural obelisk, are formed of a volcanic agglomerate—fragments of solid or scoriaceous basalt, embedded in a dull, dark-green, "paste" once a volcanic dust. They, like others in the neighbourhood, are the ruined fragments of volcanic cones, which, like some of those near Clermont-Ferrand, formerly forced their way through, and were built up on, the lacustrine deposits accumulated in valleys excavated from much more ancient rocks.

But to study this stage of volcanic ruin we need not go so far as Auvergne. Better or more instructive examples cannot be found than are afforded by some parts of our own country, notably the coasts of the Firth of Forth. The classic examples of Arthur's Seat and North Berwick Law rise on the southern side ; on the northern they stud the margin of Fifeshire, more especially from Queensferry to near Kirkcaldy, and from Largo to St. Monans. Here we find indications of contemporaneous volcanic action in the earlier half of the Carboniferous period—lava-flows and tuffs intercalated among ordinary sediments ; but more interesting still, and yet more directly related to our present purpose, are the ruined cones. Of these there are dozens, from very small to comparatively large. They are referred by geologists to the Permian period, during part of which puys must have been as abundant in that district of Scotland as they are still in Auvergne.

These ruined volcanoes, for purposes of description, may be arranged in two groups—those which form rather prominent hills, and those which are inconspicuous in the landscape. The former are the less numerous. They are often composed of a mass of basalt, on the flanks of which scattered remnants of agglomerate can be detected. The one probably represents the "plug," or solidified lava, which at last choked the throat of the crater; the other, some fragments of the surrounding cone. Among these puys one of the most remarkable and perfect is Largo Law. This has been very clearly described and illustrated by Sir Archibald Geikie in his important work, *The Ancient Volcanoes of Great Britain*[1]; but as I have only seen it from a distance I shall select for description one more accessible and more widely known,—Arthur's Seat, near Edinburgh,—although the interpretation which I adopt is not universally admitted. All geologists, however, agree that the hill is a remnant of an ancient volcano; the point in dispute is whether the outbreaks were continuous or whether, as was the case in some parts of Auvergne, they were separated by a very considerable interval of time. The evidence appears to me favourable on the whole to the latter view.[2]

Adopting this, Arthur's Seat may be thus described

[1] See chapter xxxi.

[2] Professor Edward Forbes, Sir A. Geikie, and the majority of geologists maintain that there were two distinct epochs of outbursts. Charles Maclaren (in the later part of his life) and Professor Judd adopt the view that there was but one.—*Quar. Jour. Geol. Soc.*, xxxi. (1875), p. 131.

when looked at from the north. Three rudely parallel ridges, of which the eastern is the highest, form a pair of shallow valleys, which are blocked at their heads by a roughly pyramidal mass, compared from some points of view to the outline of a sitting lion. The western ridge, the well-known Salisbury Crags, is formed by a sheet of dolerite intruded among sandstones and shales of Lower Carboniferous age. Another intrusive mass (the Dasses) crops out here and there on the opposite flank of the western valley (the Hunters' Bog), and the escarpment of the ridge above is formed by a basalt-flow, the earliest of the contemporaneous ejections. The narrower eastern valley is excavated out of more or less ashy shales, which pass up into coarse tuffs, succeeded by great sheets of lava; most of these, however, are not basalts but porphyrites. All this may be regarded as the remnant of an old plateau, built up chiefly of lava-flows, of which Calton Hill is almost certainly another fragment. The pyramidal hill is a great mass of agglomerate, the blocks of which are sometimes quite a cubic yard in volume. This is pierced by some intrusive masses, of which the most important are the very compact basalt which forms the actual summit—supposed to be the plug of the old crater—and a mass of rather porphyritic basalt on the north-western side, often called the Lion's Haunch. The hill is regarded as a ruined puy, thrown up in a volcanic region, which had been already sculptured by meteoric agencies. Those, however, who agree

with Professor Judd regard it as only a fragment of the ancient throat, from which the tuffs, basalts, and porphyrites already mentioned were discharged: not during the Permian or some later period, but in Lower Carboniferous ages.

Similar ruined cones, the structure of which is indisputable, are abundant in other parts of Scotland. North Berwick Law, often so conspicuous an eminence from the wider part of the Firth of Forth, might almost be mistaken for an extinct volcano, so peculiar is its outline. It is, in fact, the remnant of one, for it is built up of trachytic ashes and lavas, though its present form is due to the sculpture of wind and weather. North Berwick Law, however, seems to have been a volcano of Lower Carboniferous age, not one of the more modern puys. But the latter are not uncommon in Ayrshire, Nithsdale, and Annandale. "These Permian necks are, on the whole, smaller than those of the Carboniferous period. The largest of them in the Ayrshire and Nithsdale region does not exceed 4000 feet in longest diameter. The great majority are much less in size, while the smallest measure twenty yards or even less. . . . These necks, from their number and shape, form a marked feature in the scenery. They generally rise as prominent, rounded, dome-shaped, or conical hills, which, as the rock comes close to the surface, remain permanently covered with grass. Such smooth green puys are conspicuous in the heart of Ayrshire, and likewise farther south, in the Dalmellington coal-field, where some of them are

locally known as 'Green Hill,' from their verdant slopes, in contrast to the browner vegetation of the poorer soil around them."[1]

Turning to the second group, those which as a rule make no conspicuous figure in the landscape, we come to the volcanic pipes, or "necks," which are so abundant in certain districts on the Fifeshire coast. Nowhere can they be better studied than between St. Monans and Elie, especially when the tide is low. This district is one of the most interesting in Great Britain to the geologist, and is not without its attractions for the antiquarian. The shore and cliffs are formed of regularly bedded sandstones and shales of Lower Carboniferous age. These are occasionally cut by dykes of dolerite or basalt, which themselves sometimes well repay study.[2] But the continuity of the stratified rock is frequently interrupted by masses of agglomerate. Some of them cut through the strata, as they are exposed in the cliff, like the shaft of a mine which has afterwards been filled up by dark rubbish; others interrupt the continuity of the beds which crop out on the shore. Sometimes they rise only a little above the rocky floor, like a dark cushion or mat; sometimes they stand up from it in low craglets or skerries. These necks, of which vertical sections are exposed in the one case and horizontal in the other, are cleanly drilled through the sedimentary

[1] Sir A. Geikie, *Ancient Volcanoes of Great Britain*, chap. xxxi., vol. ii., p. 63.

[2] Here, as in other parts of Fifeshire, the extremely decomposed variety called "White Trap" is rather common.

rock "as if with an auger," though sometimes the strata are much twisted or shattered in the immediate neighbourhood, and occasionally, in the vertical sections, are distinctly bent down at the ends on either side. The explanation of this structure may be deferred to a later part of this book. In certain cases

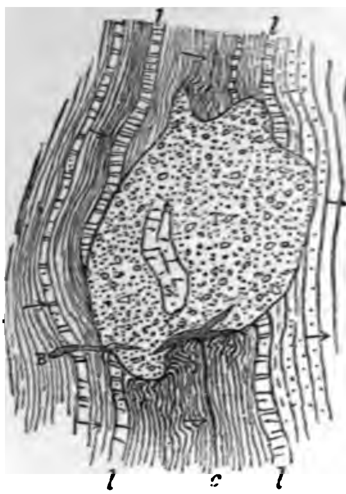


FIG. 13. PLAN OF VOLCANIC NECK ON BEACH AT ST. MONANS (Sir A. Geikie).
T, Basaltic tuff enclosing sandstone fragment (S), breaking through sandstones, shales with limestones, (l), and coal seam (c); B, Basalt dyke. The arrows show the direction of the dip of the strata.

the ground-plan is almost an oval or a circle, as shown in the annexed diagram; but more irregular forms also occur, and in some of these last the centre of discharge appears to have shifted slightly,[1] as may be

[1] Sir A. Geikie gives a diagram of Volcanello in the Lipari Islands, showing that discharges have taken place from three points very near together along a line.

seen in more modern volcanic districts. These necks in Fifeshire may be anything between a few yards to something like three quarters of a mile in diameter. The contents vary in nature and in size, and no connection appears to exist between the magnitude of a vent and that of the materials by which it is filled. These vary from fine tuffs to coarse agglomerate; they are partly igneous, partly stratified in origin; the former usually much predominating, though in one or two of the smaller necks, as in certain of the Eifel volcanoes, fragments of the country rock are extremely abundant.[1] The volcanic material consists of subangular pieces of basalt more or less scoriaceous, often from about a cubic inch downwards in volume,[2] which are set—frequently very thickly—in a paste of finer fragments and dust, the whole forming a dull-green rock, spotted with black, which is more or less crumbling in texture, and is often traversed by thin veins of calcite. The aspect of the mass as a whole is so characteristic that one of these necks can be recognised by a practised eye from a considerable distance. Faint traces of stratification may be occasionally perceived in these masses of agglomerate, which sometimes appear to become coarser towards the middle. Sir A. Geikie figures one in which a concentric structure may be clearly recognised. But this matrix encloses other fragments than those just named, and these occasionally attain a larger size.

[1] That is the case in the neck represented on Plate XII.

[2] "Bombs" of larger size sometimes occur.

Plate XII. A Volcanic Neck, near Airdross Castle, Fifeshire.

In some of the necks blocks of indurated ash, not seldom very regularly stratified, are far from uncommon, and these may be several cubic feet in volume. Bits of sandstone, shale, and other sedimentary rocks occur, sometimes very abundantly,[1] in certain of the necks. In a few cases these also are large; often they are considerably indurated, or even more distinctly altered. Some effect is also produced on the sedimentary strata in the immediate vicinity of the neck, but this, usually, is by no means great. Sir A. Geikie suggests that here the change may not be due to the actual eruption, but may be the effects of hot water discharged during the solfatara stage. Any alteration, however, of the fragments which form part of the agglomerate is more probably the direct result of heat, but as a rule the temperature does not appear to have been very high. Professor Heddle has endeavoured to ascertain the amount. "He found that the bituminous shales have lost all their illuminants, and of organic matter have retained only some black carbonaceous particles; that the encrinital limestones have become granular and crystalline; that the sandstones present themselves as quartzite; and that black carbonaceous clays show every stage of a passage into Lydian stone. He inferred, from the slight depth to which the alteration has penetrated the larger calcareous fragments, that the heat to which they were

[1] Sir A. Geikie (*ut supra*, chap. xxvii.) mentions a few cases in Lanarkshire and Perthshire where the necks were wholly filled by fragments of stratified rock. The majority of the fragments in the one represented in Plate XII. consist of stratified rock.

exposed must have been but of short continuance.[1] As the result of his experiments, he concluded that the temperature at which the fragments were finally ejected from the volcanic vents probably lay between 660° and 900° F."[2] These masses of agglomerate are not infrequently cut, like the adjacent sedimentaries, by basalt dykes, and are slightly indurated in consequence near the surfaces of contact.

But while this part of the Fifeshire coast produces the finest assemblage of volcanic necks, some of great interest occur elsewhere. One of these, the famous Rock[3] and Spindle, about two and a half miles to the east of St. Andrews, has long been prominent in most text-books of geology. The former is a pinnacle of basaltic agglomerate, which rises from the shore to a height of some forty feet. The Spindle is part of an intrusive mass of basalt, which has here taken a cylindrical or possibly drop-like shape, so that the columns, formed as it cooled, and now exposed to view, appear to radiate from a centre like the spokes of a wheel. Both the one and the other are cut by another basalt dyke, about a couple of feet in thickness.

The coast on either side of Burntisland also affords

[1] In the Eifel I have often noticed that the fragments of slate, etc., are but little changed. In one case the thin edges were sometimes slightly glazed, the rest not being conspicuously affected.

[2] *Trans. Roy. Soc. Edin.*, xxviii., p. 487, summarized by Sir A. Geikie, *ut supra*, chap. xxxi. (vol. ii., p. 78). So far as my observations go, even the intrusive masses of basaltic rock in Fifeshire generally produce little more effect than is described above.

[3] The word "Rock" here means "Distaff."

FIG. 14. ROCK AND SPINDLE NEAR ST. ANDREWS.

xcellent opportunities for the study of ancient lava-ows, necks, and intrusive masses, which probably ere more or less connected with them. These, owever, in some cases, undoubtedly belong to the ower Carboniferous age, and with such Sir A. Geikie lasses one of the most striking examples of a volcanic eck—the Binn of Burntisland. This huge pile of olcanic material—for though the ends of the short dge are distinguished as the east and the west Binn, ey can hardly be separated—descends from a short

FIG. 15. SECTION FROM EAST TO WEST ACROSS THE BINN OF BURNTISLAND. (Sir A. Geikie)
1, Sandstones; 2, Limestone; 3, Shales, etc.; *b*, *b*, interbedded Basalts; *t*, *t*, bedded Tuffs; T, Tuff of the neck; B, Basalt veins.

distance below the summit,[1] in steep cliffs, for nearly 500 feet, almost to the level of the old sea-bed on which the little town is built. Though precipitous in many parts of the face, it can be examined by anyone accustomed to scrambling, and admirably illustrates the composition of a volcanic hill. It consists of basaltic ash and agglomerate, full of fragments of lava and masses of scoria, which generally do not exceed a few inches in diameter, and are often much less. With this are irregularly mingled fragments of fresh-water limestone, shale, and sandstone, frequently little, if at all, altered. The mass often exhibits a rude stratification, such as may be observed in any dissected cone. Indurated in the lapse of time, it is traversed by rude joint-planes, and the blocks under the action of the weather present a rough resemblance to huge woolpacks. They also exhibit locally a spheroidal structure on a smaller scale. Here and there a dyke traverses this great mass of agglomerate,

[1] The highest part is 631 feet above sea-level.

but they are not numerous. Though masses of lava, both intrusive and contemporaneous, are frequent in the neighbourhood, this vent or group of vents must have ejected little more than volcanic dust and scoria, with some fragments of the sedimentary rocks through which it had been opened. Here and there small corries have been worn by the rains in the face of the cliff, and when standing in one of these, as Sir A. Geikie justly remarks, we can form a fair idea of the aspect of a crater in these volcanoes of Carboniferous age. Both fragments and matrix have been affected to some extent in colour and texture by the action of water during the long ages which have elapsed since first they were ejected; nevertheless, as the cohesion of the surface is destroyed by the weather, the ancient scoria and dust crumbles under the foot and rattles down the slope, as it does on the cone of Vesuvius or the Puy de Gravenoire in Auvergne. But in no one of these fragments of volcanoes, either in England, Scotland, or Ireland, can any remnant be discovered, so far as I am aware, of an actual crater, unless possibly in one or two of the latest Tertiary outbursts.

We might continue the study of dissected volcanoes in other parts of the British Islands and in geological ages both more remote and more recent than the periods of which we have spoken. But these may suffice, for we shall have to refer to some of the more important among the rest in the chapter on the volcanic history of Great Britain and Ireland. This one

may be ended by a few remarks on the intimate connection between the materials of strictly volcanic origin and the more deep-seated masses of igneous rock, which in many cases may never have reached the surface.

Of this transition from coarsely crystalline rock to lavas and agglomerates, instances may be found on careful search in more than one part of Britain—perhaps the best, according to Professor Judd,[1] being Ben Nevis, the well-known monarch of the Scottish Highlands. The lowest part of this mountain consists of more than one variety of fairly coarse crystalline granite, traversed by veins of finer-grained granite and felstone, or of crystallised quartz and felspar. "The granitic rocks constitute those great spurs, with sharp summit ridges and steeply sloping sides, which divide the deep corries that form so striking a feature. . . . Some distance above the well-known lake, which lies in a hollow upon the shoulders of the mountain, a remarkable change is found to take place in the character of the granitic mass; it becomes much finer grained, and as we still ascend we find the hornblende and mica gradually disappearing, till in the end the rock becomes a granular felsite of a pale-red colour, and often more or less porphyritic in structure. The highest portion of the mountain, however, is composed of a mass of rocks of totally different character. Instead of the pale-red granites, eurites, and felsites, we find dark-blue, grey, greenish, and pur-

[1] *Quar. Jour. Geol. Soc.*, vol. xxx. (1874), p. 293.

plish felstones, and associated with these are enormous masses of volcanic agglomerate, composed for the most part of angular fragments of all sizes, of felspathic materials, heaped together in the wildest confusion, and compacted into masses of great solidity and hardness."[1] Professor Judd then proceeds to bring forward other evidence in favour of a connection between, and a general continuity in the history of, these igneous rocks, leading to the conclusion that Ben Nevis is the degraded stump of a great volcano of Old Red Sandstone age, and also exhibits the solidified underlying igneous masses which supplied the ejected lavas and agglomerates.

The district of Schemnitz, in Hungary, has been described by Professor Judd[2] as illustrative of the same phenomena on a still grander scale. Its igneous rocks vary from ashes and lavas to coarsely crystalline masses. The volcano with which these are connected must have once covered an area about fifty miles in diameter, and its outer portion—a broad girdle consisting of lava-flows with associated agglomerates and tuffs—has been reduced by denudation to a number of more or less isolated mountain-masses, rising from 3000 to 4000 feet above sea-level, and

[1] A fragment of the actual summit, given to me by Mr. E. Whymper, lies before me as I write. It is a nearly black rock of rather vitreous aspect, sparsely spotted with small crystals of felspar, as fresh-looking as not a few andesites which I have from time to time examined from districts in which volcanoes are still in activity. Several of the specimens which Mr. Whymper brought from the Ecuadorian Andes were not nearly so well preserved.

[2] *Quar. Jour. Geol. Soc.*, xxxii. (1876), p. 292. The account is condensed from my friend's paper, and his words have been followed as nearly as possible.

overlooking a central depressed area, in which are situated the mining towns of Schemnitz, Kremnitz, and Königsberg. This is traversed by the deep valley of the Gran, an affluent of the Danube. These lavas are andesites, but they exhibit several varieties, not excluding representations of the quartziferous or dacite group. Professor Judd states that they present a very striking resemblance to the porphyrites of Devonian or Carboniferous age in Scotland, and that rocks of a precisely similar chemical and mineralogical character are being ejected by the volcano of Santorin at the present day. These lavas, in the central part of their masses, are often found to assume a very coarsely crystalline and almost granitic character, while their outer portions present a strikingly scoriaceous or slaggy appearance. The associated fragmental rocks vary from extremely coarse agglomerate to the most perfectly stratified tuffs, some of which occasionally contain the remains of plants, and thus prove that the outbursts occurred in the Miocene, or Upper Miocene of the older authors, and when a warm-temperate climate prevailed. But in the central area, within the great girdle of lavas and ash-beds, stratified rocks of earlier date are found, both Eocene and Lower Trias, often greatly affected by contact metamorphism, together with large intrusive masses, varying from compact to coarse-grained. The latter, of which there are many varieties, often cut through and metamorphose the Triassic beds. In some places they are much decomposed, obviously by the passage of acid

vapours, and besides this are highly metalliferous. The more compact varieties pass gradually into the coarse-grained, and thus evidently represent a magma which is substantially the same, but has solidified under different conditions. The most compact varieties are undoubtedly closely related to the above-named Miocene andesites, while the most coarsely crystalline are either a diorite or a tonalite.

Again, the more compact igneous rocks, whether of the inner or the outer area, are cut by a number of intrusives. The earlier of these are very acid rocks, rhyolites, pitchstones, etc., which also pass in places into more compact varieties, "almost identical with many quartz-porphyries of the older geological periods," while the later are markedly basic basalts. These occur sporadically, as isolated puys of small size, now indicated for the most part by their central plugs of lava.

Professor Judd gives a sketch of the geological history of this volcanic region. Its age of fire, as indeed was the case in other parts of Europe, occurred in the Miocene period. Prior to this, indeed, some isolated outbursts took place in Silesia and even in Hungary, over which we need not now linger. But the great series of eruptions began at the outset of the Miocene. By them a cone of huge dimensions was gradually built up, which eventually covered an area nearly fifty miles in diameter. This, like Etna, consisted of an enormous central mountain, upon the sides of which innumerable parasitic cones had been

formed, each pouring forth its lava streams. The period of continuous and violent eruptions appears to have been terminated by a paroxysmal outburst on a prodigious scale, which reduced the great Schemnitz volcano to a crater-ring of vast dimensions—a basal wreck like those described by Darwin in some of the Atlantic islands.[1] This great paroxysmal outburst was succeeded—as has often been the case—by a considerable subsidence of the ruined mass. By that the whole area, excepting the highest portions of the shattered crater-ring, was submerged beneath the waters of a sea (probably an inland one, like the Caspian), which found their way into the interior. The ruins, as may be seen in an Atlantic "caldera," became the sport of the waves, from which they rose as islands, not unlike those of the Greek archipelago. In this condition fresh volcanic outbursts occurred, though on a more limited scale. Those in the Schemnitz district were almost confined to the lagoon which occupied the crateral hollow of the shattered mountain. "At this period of its history the volcano of Schemnitz must have presented a striking resemblance to what is now exhibited by Santorin." The formation of these scattered cones, from which at first lavas of a very acid character were ejected, and at a later stage the basalts, was the last important effort of the volcanic forces. Afterwards their declining energies were only equal to the origination of fumaroles and

[1] *Geological Observations*, part I., chap. iv. He hesitates, however, to accept the explanation of their formation which is given above.

hot springs, with which probably the noted mineral veins of the district are connected. Occasional earthquake shocks show that even now the volcanic forces are not completely exhausted.

Intrusive masses sometimes assume a very peculiar form, which, as it occasionally may be connected with a volcanic eruption, may be mentioned in conclusion. As a rule, the volcanic orifices (though satisfactory evidence on this point is not easily obtained) appear to be connected with a subterranean reservoir of molten rock, which in solidifying assumes a coarsely crystalline condition, becoming, according to its chemical composition, granite, gabbro, or the like. This mass is often exposed by subsequent denudation, thus forming a great boss in the middle of sedimentary rocks. The latter are more or less affected by contact metamorphism—sometimes are themselves rendered crystalline in the immediate vicinity. Their strata are generally somewhat disturbed, but this often to a surprisingly slight extent. In such case, if we assume one of these igneous masses to have forced its way upwards from the inner part of the earth's crust, we cannot easily explain what has become of the stratified rocks which once occupied the same position. Sometimes they appear to be missing over an area not a few square miles in extent. The intrusive mass cannot have squeezed the neighbouring beds in a lateral direction outwards, for in that case they must have been greatly crumpled and doubled up, and of such disturbance there are often no signs. They may

have been lifted up bodily, as a valve or lid is raised by the pressure of a fluid in a pipe; but if so, the amount of denudation in some cases must have been so extraordinarily great that this hypothesis seems to be hardly satisfactory.

But another explanation has been proposed, which not infrequently may prove applicable. It was brought into prominence about twenty years ago by an eminent American geologist, Mr. G. K. Gilbert,[1] but attention had been previously called to the same thing by Mr. C. Maclaren,[2] of Edinburgh. This structure, which was named a laccolite by the former, may be described as a peculiar modification of the intrusive

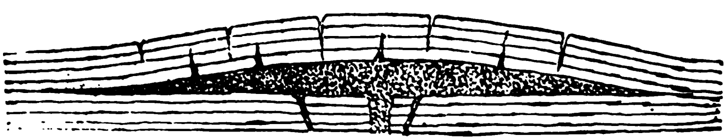


FIG. 16. DIAGRAMMATIC SECTION OF A LACCOLITE.
The intrusive rock is dotted thickly.

sill. A mass of igneous rock, in forcing its way towards the surface, at last may reach a spot where progress in a lateral direction becomes less difficult than in a vertical one—in other words, where it is more easy to lift the superincumbent strata bodily than to break through them. If that be so, the molten rock will spread laterally round the orifice by which it has hitherto ascended, and if its material be in a

[1] "Geology of the Henry Mountains," *U. S. Geog. and Geol. Surv.*, chap. ii.

[2] *Geology of Fife and the Lothians*, p. 100 (1839).

rather viscid condition, or if new supplies be successively injected from below, the intruded mass will be rather thick, at any rate in its central part, in comparison with the area which it covers. It assumes the form, if we may venture on a rough comparison, of a mushroom, the stalk of which represents the supply-pipe. In some cases the discharge may take place from a fissure, so that the comparison will only hold for a cross section of the laccolite. In others—and these perhaps the more numerous—the lava cistern may be filled from a number of dykes, the underlying mass of sedimentary rock having been greatly shattered. Occasionally the overlying strata also may be fissured during an uplift. Thus dykes would be formed which in some cases might even reach the surface; if so, a laccolite might be connected with a volcano, though this, so far as we can tell, is unusual. Commonly it must have produced a low, dome-like upheaval of the overlying rock—perhaps a slight cracking of the ground, accompanied by an escape of vapour or hot water. That molten matter does make its way for considerable distances by underground channels, and with less disturbance of the adjacent rocks than we should have expected, is proved by numerous facts. Of these, two which have been already mentioned may serve as examples, viz., the great lava stream from Kilauea in 1840, and the singularly level sills which are exposed on the eastern coast of Skye. Laccolites have been identified in Great Britain, one of the best marked being that which forms the mass of Corndon

Hill, in Shropshire; and it is quite possible that this may also be the nature of some of the larger masses of coarsely crystalline igneous rocks.

A study of volcanoes which, as described above, have been dissected by the hand of nature, and can be examined by the geologist, like a series of anatomical preparations illustrative of the human body, leads us to the following general conclusions:

1. A cone, with its crater, is formed by explosive discharges of scoriaceous materials, large and small, from an orifice in the earth's crust.

2. From this orifice lava also may be discharged, either by overflowing or by breaching the cone, or it may issue from one or more fissures, generally in the immediate neighbourhood, though in some cases flows of this kind have no connection with any cone of importance.

3. These outpoured masses of lava sometimes flow to great distances, but occasionally they appear to have emerged in such a pasty condition as to have been arrested by solidification very near, or immediately over the orifice. Sometimes, also, a small cone with a shallow crater may be built up of lava alone, and cones with a low angle of slope generally contain a less proportion of fragmental materials than those with a comparatively high angle.

4. Craters are occasionally formed by explosive action, accompanied by very little, if any, discharge of lava and by a comparatively small amount of scoria, when the rocks in which the orifice has been formed

are sedimentary. In like manner, portions of a volcanic mountain may be blown away, when, though large quantities of igneous material are sent flying into the air, the explosion is not always accompanied by the ejection of much new material. This process may also be associated with engulfment, and sometimes the latter may predominate.

5. When a cone is in an advanced stage of denudation it may be found to consist, if small, wholly or almost wholly of scoria and volcanic dust, which has gradually become solid. But in those of larger size, where dykes and lava masses are more abundant, we commonly come down sooner or later to a core of the latter material, which seems to have plugged the original vent. Appearances suggest that this is connected with some reservoir of a similar material, though in a different stage of crystallisation, which is situated at a greater depth in the earth's crust.

CHAPTER IV

THE GEOLOGICAL HISTORY OF VOLCANOES

NOTHING like a perfect crater remains in the British Isles, but fossil volcanoes, as they may be called, belonging to various geological ages, are found in many quarters. A brief account of them may bring out certain facts which may be useful for theoretical purposes. But in a book of this size we must restrict ourselves to these islands; nevertheless, their story may be taken as a type of others, and is true, with changes in detail, for more distant regions. A mere outline will suffice to bring out the more important facts, and any attempt to enter into minute details has been rendered needless by the appearance, since I began to write, of Sir A. Geikie's monumental book on *The Ancient Volcanoes of Great Britain.*[1] It will be understood that I shall reckon as instances of volcanic discharge only cases in which dust and scoria have been ejected or lava has flowed, either in the open air or on the bed of the sea. These I shall

[1] Of this admirable work I have availed myself freely in writing the present chapter. I may, however, say that the subject is one to which I have myself devoted considerable attention, and thus have ventured to take a slightly different view on one or two points of detail from that distinguished author.

accept as proofs of volcanic action, although we cannot in all cases determine the exact position of the actual centre of discharge; but I shall not pay any attention to the more coarsely crystalline intrusive rocks very commonly associated with these, because, although very possibly some of them indicate the reservoirs from which volcanoes have been supplied, we are unable in most cases to prove that the incandescent material ever in reality reached the surface.

The earliest proofs of volcanic activity that can be recognised in Great Britain belong to a very remote age in geological history. Whether they all belong to one period, or whether some should be referred to the earliest days of the Cambrian period, and others to one yet older,—that is, whether the one should be placed at the beginning of the Palæozoic era, and the other towards the end of the Archæan,—is still a matter of dispute. Some of them unquestionably are more ancient than a deposit which, at the present time, is generally held to form the base of the Cambrian system; and I am myself of opinion, for reasons on which it is needless to enter, that all more probably are coeval, and should be counted as pre-Cambrian. In enumerating them I shall place those first which have been generally admitted to belong to that age.

The Wrekin, Caer Caradoc, Hartshill, and the south-east of the Lickey Hills in Warwickshire, Pontesbury Hill, with the adjacent parts of the Longmynds, and the ground east of the Herefordshire

Beacon in the Malverns (in all probability) indicate the position or proximity of volcanic vents of late pre-Cambrian age. The materials ejected—lava, agglomerates, and ashes of various kinds—are mostly of an acid type, and may be described comprehensively as rhyolites.[1] Probably contemporaneous with these were the groups of volcanoes near St. David's and those in the northern parts of Carnarvonshire, extending from the neighbourhood of Bangor by Llyn Padarn for a considerable distance towards the south-west, which latter ejected lava-flows and ashes of almost identical chemical composition with those of the Wrekin. Charnwood Forest in Leicestershire marks the position of another important group of volcanoes, not improbably of the same age, though direct evidence is wanting. A boring at Orton in Northamptonshire proved that this group extended at least twenty-five miles in a south-easterly direction. These last rocks, however, so far as they have been analysed, are in composition a little nearer to those called dacites than to the rhyolites.[2]

If we are right in assigning all these volcanic relics to the close of the Archæan era, we find at present no evidence of any such action during Cambrian ages in Great Britain. That seems to have been a period of quiet and steady subsidence, such as not infrequently follows one of eruption on a large scale.

[1] Some must have been very glassy. All now are devitrified; but throughout I shall exclude the effects produced by lapse of time and other agencies, and use the names to which the rocks must have been formerly entitled.

[2] H. J. Eunson, *Quar. Jour. Geol. Soc.*, xl. (1884), p. 482.

It is not till we come to the Ordovician period (or Lower Silurian of some geologists) that the peace of Britain was once more broken. Then in its earliest epoch, the Arenig, the Titans again broke prison. Lava streams flowed, ashes were ejected, probably from many points in the more central region of Wales. Moel Wyn, Manod, the Arenigs, the Arans, and Cader Idris mark a curving line of volcanic foci about forty-five miles in length. The materials on the whole are rather acid in character, the percentage of silica sometimes rising unusually high. In the Bala age, after a peace of some duration, a new series of vents opened farther to the north, the remains of which may be traced through the hill country, from the lower part of the valley of the Conway, through Snowdon, into the Lleyn Peninsula.[1] Here also the materials are rhyolite, or, at any rate, some variety of trachyte. Volcanic vents, though probably of a less important character, existed at each of these two ages in the neighbourhood of the Berwyn hills, east of the upper stream of the Dee. In the Shelve and Corndon district of Shropshire great beds of ashes prove that discharges of volcanic materials occurred late in the Arenig, in the Llandeilo, and in the Bala epochs. These were trachytic. The Breidden hills to the north mark the site of andesitic volcanoes of Bala age. In Llandeilo times there was a volcanic centre near Builth, from which trachytic materials

[1] There are signs of volcanic action, probably of Bala age, upon the north coast of Anglesey.

were ejected, as well as at two or three spots more or less to the south-west. In fact, it seems possible to trace a line of volcanic disturbance for a rather long distance in this region, which, however, was probably not of the first importance.[1] Groups of active vents existed in Pembrokeshire. One near Fishguard began during the earlier part of the Llandeilo epoch, and continued intermittently into the Bala. Here also the ejected materials were trachytes. Another, probably more or less contemporaneous, was near the coast of Abereiddy Bay, and two at least were active in Southern Pembrokeshire, among which the lavas of Skomer Island are of especial interest. In the Lake district volcanic rocks appear in great force; they form that broad band of mountains which stretches diagonally across it, between the foot of Derwentwater and the head of Windermere; they occur on the northern side of Skiddaw in the direction of Cockermouth; they are found at the Cross Fell inlier on the western flank of the Pennine chain, and are exposed, east of its watershed, beneath the Carboniferous limestones of Upper Teesdale. Obviously, then, this volcanic group, which was active more especially in Llandeilo times, beginning at the close of the Arenig and continuing into the Bala epoch, extended over a wide area. The quantity of the ejected material was also very great; in places more than a mile in vertical thickness.[2] It

[1] See Sir A. Geikie, *Ancient Volcanoes*, vol. i., pp. 203–205.

[2] On this point there is considerable difference of opinion; the maximum thickness has been given as low as 5000 feet and at least as high as 12,000 feet. Sir A. Geikie (*ut supra*, p. 228) thinks it probably does not exceed 8000 or 9000 feet.

consisted of dust, ashes, and lavas—trachytes (usually andesites, though occasionally rhyolitic), but in certain instances basalts.

During Arenig and Llandeilo times volcanic vents, also discharging andesites and occasionally basalts, existed in Southern Scotland over a large area, extending from the Ayrshire coast as far east as Peeblesshire. The ejected materials vary from basalts to (more commonly) andesites, but in Bala times some local discharges of a rather more acid rock occurred in the last-named district. Volcanoes probably existed also on the southern border of the Highlands, but the investigation of these is not yet completed.

In Ireland, as Sir A. Geikie has observed, the development of volcanic rocks in Ordovician times "in the north resembles that of Scotland, in the south it corresponds rather with the volcanic districts of Wales." Tyrone probably exhibits a continuation of the series just mentioned as occurring on the south side of the Highlands, and there are some outbreaks of Bala age in Down; but the evidence is far more clear on the south-east part of the island, where, as we get farther from the north, the volcanic materials become more abundant. Ashes or tuffs with lavas have been recognised on the borders of Louth and Meath, at the Chair of Kildare, in Wicklow, Wexford, and Waterford, the most remarkable group being in the last-named county. The materials are trachytes (often andesites) and occasionally basalts. They are assigned to the Llandeilo and Bala epochs, which

in this region are often difficult to separate. Some, however, of these discharges, according to Sir A. Geikie, may possibly belong to a later age. Volcanic vents also have been detected in the west of Ireland, between Lough Mask and Killary Harbour; these, which are, generally speaking, trachytes, are assigned to the Bala epoch.

During the Silurian period tranquillity prevailed in England,—unless possibly some basaltic rocks at Tortworth in Gloucestershire belong to its lowest division, the Upper Landovery,—indeed, in all parts of Britain, excepting in the extreme south of Ireland, where the former existence of volcanoes has been proved by the discovery of trachytic lavas, agglomerates, and tuffs.

During the period when the Devonian or Old Red Sandstone rocks were deposited, Wales and the greater part of England were free from volcanic eruptions. The south-west region, now Cornwall and Devon, was occupied by a sea, probably rather shallow; north of this was a considerable tract of land, which became more elevated in that direction, and ultimately rose into mountains, probably lofty. This tract in places surrounded large sheets of water. These, apparently five in number, were mostly fresh, but the one which occupied the more southern part of Wales may have communicated with the sea. Tuffs and sheets of lava, including both trachytes and basalts, occur at several localities in South Devon, and with these some at least of the yet more numerous intrusive igneous rocks of the district

most probably are connected. The evidence indicates that outbreaks began in the Middle Devonian and continued into the Upper Devonian.

In Scotland very different conditions prevailed. There, for a long time, earth movements on a grand scale had been in progress. When they began we are as yet unable to determine, but probably it was either during or towards the end of the Ordovician period. It is also doubtful whether the movements were continuous or interrupted by protracted intervals of rest; but we cannot be wrong in believing that by the end of the Silurian period a mountain chain had been upreared, the carious remnants of which are now represented by the central and north-west Highlands. The southern Uplands may have been formed either as a line of foothills or as a subordinate group, related to the principal chain much as the Jura is to the Alps, and each of these at that time must have far out-topped its present altitude. Both are formed of rocks which bear witness everywhere, in their contortions, foldings, crushings, and faultings, how intense were the pressures to which they had been subjected.

The Old Red Sandstone has been separated into two subdivisions, between which a marked unconformity often exists. This indicates some recurrence of earth movements, though probably on a minor scale. According to Sir A. Geikie, who has made a special study of this formation, its deposits are of fresh-water origin and form five groups, which

he considers indicative of as many lake-basins. The most northerly extended over the Orkney and perhaps the Shetland Islands, together with the basin of the Moray Firth. To this, for purposes of reference, he gives the name of Lake Orcadie. The next, called Lake Lorne, probably was deposited in a smaller basin. It lay in the west of Argyllshire, "extending from Loch Creran to Loch Melfort and the hills on the west side of Loch Awe." Between the central Highlands and the southern Uplands lay the great sheet of Lake Caledonia,[1] which stretched across Scotland from the east coast even into Ireland as far as Loch Erne.[2] The fourth, called Lake Cheviot, is represented at the present day by the hills bearing that name and by the sandstones in Berwickshire, but it probably extended eastwards for a considerable distance. The fifth occupied a part of Southern Ireland, including Killarney and the eastern hills of County Kerry. The first and last of these areas were comparatively free from eruptions, although of late years a few small volcanic groups have been detected in the former; the South Wales estuary also was entirely free, but tuffs, ashes, and lava-flows abound in the other three.

Sir A. Geikie[3] calls attention to a feature in the position of these volcanic vents, which, as he says,

[1] Perhaps as large as Lake Erie in North America.—Sir A. Geikie, *ut supra*, vol. i., p. 296.

[2] Professor Hull separates the deposits in the north-west of Ireland under the name of Loch Fanad.

[3] *Ut supra*, vol. i., p. 272.

becomes increasingly distinct during the long series of Palæozoic eruptions which now commences, namely, "the persistence with which the vents have opened in the valleys and have avoided the high ground. . . . With regard to the Old Red Sandstone of Central Scotland, though the lavas and tuffs that were discharged over the floor of the sheet of water which occupied that region gradually rose along the flanks of the northern and southern hills, yet it was on the lake bottom and not along the hills that the orifices of eruption broke forth." Sometimes, as he remarks, these valleys may correspond with faults, which would obviously be places of weakness in the earth's crust, but in not a few instances it can be shown that the imprisoned material has not escaped along lines of fault, visible at the surface, even when such existed in the neighbourhood, so that any fissures which offered a passage upwards to the volcanic ejections must have lain far beneath the rocks which now form the surface of the ground. No undoubted vents, he adds, have been detected as yet among the Highland hills, on the one hand, or the southern Uplands on the other. The frequency of dykes, however—their rock closely corresponding with that which elsewhere forms the lava-flows—indicates, I think, that these regions, and more especially the former, were not by any means at rest.

Many geologists think that some at least of the great granitic masses of the Highlands indicate the

supply basins of vanished cones and craters.[1] The volcanic disturbances were confined, almost without exception, to the Lower Old Red Sandstone, and the lavas with their fragmental associates, which were then ejected, are almost exclusively andesites; occasionally they are quartziferous, or have been dacites, but these, as Sir A. Geikie remarks, are comparatively rare; they are seldom sufficiently basic in composition to be ranked among the basalts.[2] The tuffs, however, sometimes have a more acid character than the lavas.

The most northern limit of the volcanic rocks of Lower Old Red Sandstone age is the islet of Uya, in Shetland; its southern is in the Cheviot hills of England, a distance from north to south of about 250 miles. In Lake Orcadie were four groups of volcanoes, namely, in Shetland, in the Orkneys, at Buckie, and at Strathbogie. In no case are they large, so we may pass over these and the more important vents of Lorne, which have not yet been fully described, to the far grander volcanoes of Lake Caledonia. These were most active towards the middle of the Lower Old Red Sandstone, but had ceased their eruptions long before its last sediments were deposited. The following concise summary, by Sir A. Geikie,[3] indicates so clearly the grounds and

[1] For instance, Ben Nevis; see Professor Judd, *Quar. Jour. Geol. Soc.*, vol. xxx. (1874), p. 292.

[2] The silica, according to a table given by Sir A. Geikie (*ut supra*, chap. xvii.), commonly varies from about 59 to 63 per cent.; the soda exceeding the potash, though sometimes the two are nearly equal.

[3] *Ut supra*, vol. i., p. 297.

nature of the inferences in this and other like cases that I make bold to quote it. "We find evidence of a number of distinct clusters of volcanoes ranged along the whole length of the basin. The independence of these volcanic districts may be inferred from the following facts: (1) The actual vents of discharge may in some cases be recognised; (2) even where these vents have been buried we may often observe, as we approach their probable sites, a marked increase in the thickness of the volcanic accumulations, as well as a great development of agglomerates and tuffs; (3) traced in the opposite direction the volcanic materials are found to thin away or even to disappear. Those from one centre of discharge may be observed now and then to overlap those from another, but the two series remain distinct." Making use of these principles, he identifies two parallel chains of vents running along the length of the lake at a distance of about twenty miles apart, one a few miles from the northern, the other from the southern margin. The northern chain runs from the coast-line, near Stonehaven, through the Sidlaw and Ochil hills. It is then interrupted by a fault which brings in newer deposits and hides everything for nearly sixty miles; but it has been again recognised in the Isle of Arran, and yet more abundantly to the south of Campbeltown in Cantyre. Twenty-two miles away, and on the other side of the North Channel, similar volcanic rocks occur near Cushendall, on the Antrim coast, and along the same line, at a distance

of fifty miles in the interior, sheets of lava, "precisely like those of Central Scotland," are found in the hills of Tyrone. Thus this chain of grouped volcanic vents can still be traced for a total length of about 250 miles, and it may have extended some distance farther to the north-east. The southern chain cannot be followed for more than about seventy-five miles, "from the southern suburbs of Edinburgh to the coast of Ayrshire, but as its north-eastern end is concealed by Carboniferous formations, and its south-western passes under the sea, its true length is probably more." The volcanic masses, consisting largely of lavas, attain a great thickness at the northern end of the Pentland chain, where it is said to exceed 7000 feet. In this district also they are a little more variable than in others, since both potash and soda trachytes, as well as basalts, have been observed.

The volcanic rocks of the Cheviot hills are still exposed over an area of about 230 square miles. They consist largely of lavas, mainly andesitic, with comparatively thin beds of tuff. An intrusive mass of granite which forms the centre and the highest summit of the Cheviot range, is regarded as representing the deeper-seated magma from which the surface discharges were supplied. A second group of volcanoes connected with the same lake is exhibited on the coast of Berwickshire, to the south of St. Abb's Head, where the actual vents, together with the lavas and tuffs connected with them, have been

clearly exposed by denudation. They are of the usual mineral character, and it is possible that a third group may have existed inland in the heart of Lammermuir. In the south-west of Ireland contemporaneous volcanic rocks occur in the so-called Dingle beds. These, however, are more acid than the products of the Scotch volcanoes, and correspond more nearly with the Silurian lavas of the same region or with the Ordovician of North Wales. The date also of the Dingle beds, owing to the want of fossil evidence, cannot be exactly determined, but they present close lithological resemblances to the Lower Old Red Sandstone of Scotland, and are now generally considered to be of about the same age.

The Upper Old Red Sandstone was a comparatively undisturbed epoch. There were some eruptions, not on a large scale, in the Island of Hoy (Orkneys), and at two localities at Caithness, also at two localities a few miles to the south of Limerick; but, as the period was closing, a series of volcanic disturbances commenced which, though more sporadic and limited in character than those of the Lower Old Red Sandstone, affected a very large area, and continued through the Carboniferous into the Permian period. These eruptions, the last in the Palæozoic era and for a very long time afterwards, will be most conveniently described continuously and according to their geographical distribution.

Returning to the south-west of England we find at several localities among the Carboniferous rocks,—

representing the lower portion of that period,—tuffs and lava-flows, the most remarkable instance being at Brent Tor, in the neighbourhood of Tavistock, which, as described some years since by Mr. Rutley,[1] marks the site of an ancient volcano. In Somersetshire also, as in the neighbourhood of Weston-super-Mare and other localities nearer the Mendips, (though some of the igneous rocks are probably intrusive,) vents, ejecting basaltic materials, undoubtedly were in existence during the time when the Carboniferous limestone was deposited. In Derbyshire also the floor of the sea on which the same rock was accumulating was locally overspread by discharges of basalt (here called toadstone) with ashes and volcanic mud.[2] More minute work, as Sir A. Geikie observes, must be done before the geological position of these interruptions to the quiet deposition of the limestone can be precisely determined; but he shows that true necks, filled with agglomerate, are in existence, while beds of stratified ash have long been known to occur. In all probability small volcanoes broke out on the sea-bed, as happened at Graham Island or at Pantellaria in the Mediterranean. Tuffs and lavas of a like mineral character, intercalated in the same limestone on the southern coast of the Isle of Man, indicate that here also volcanic discharges took place under similar conditions.

[1] "The Eruptive Rocks of Brent Tor," *Mem. Geol. Survey*, 1878, and *Quar. Jour. Geol. Soc.*, xxxvi. (1880), p. 286.

[2] The best description of the Derbyshire volcanoes will be found in a paper by Mr. Arnold Bemrose, *Quar. Jour. Geol. Soc.*, vol l. (1894), p. 603.

Before quitting England we must notice a number of igneous rocks, widely distributed, the geological position of which cannot be determined with certainty. Undoubtedly they are later than certain Carboniferous sediments, but their precise age is a matter of inference rather than of proof. The most interesting, as well as the more nearly determinable, so far as age is concerned, occur in the neighbourhood of Exeter, one group extending from that city for about five miles to the south-west; another in the Yeo Valley, not far from Crediton; and a third, the most northerly, near Tiverton, the distance between the extreme points being about twenty-one miles. The lavas represent basalts and andesites, and a quartziferous variety is said to occur. That they are later than the Carboniferous rocks of the district, and associated with the lower part of the "Red Rocks" of Devonshire, is beyond dispute; but then what is the geological age of the latter? Formerly they were all counted as Trias, but now their lower members are generally placed in the Permian system. Hence we may assign these Devonshire outbreaks to the latter period, which was also one of great disturbance in the south-eastern Alps and in parts of Germany. Besides these, a number of patches of basaltic rocks are scattered here and there over the coal-fields of the Midland and Northern Districts, from the Clee Hills in Shropshire to the coast of Northumberland. They are certainly later than the Coal Measures, and appear in all cases except one

to be anterior to the Permian deposits, where such exist; but so far as I can learn they are not associated with volcanic detritus, and there is no conclusive evidence to show whether they are lava-flows or sills. The difficulty is increased by the fact that some of these rocks in the north of England are probably coeval with the vast outpourings of basalt in the western part of Scotland during the Tertiary era. For instance, the great Cleveland dyke runs to the sea on the Yorkshire coast after cutting the Inferior Oolite, and a dyke-like mass near Swinnerton in Staffordshire is said to break through the Keuper deposits. As a rule, however, these masses of basalt appear anterior to both the Trias and the Permian, and, whether intrusive or not (in some cases they certainly are the former), may be connected with that series—probably a prolonged one—of mighty earth movements which in this part of the world intervened between the later part of the Carboniferous and the earlier of the Permian.

We must now return to Scotland. A long truce, as we have said, prevailed during the deposit of the Upper Old Red Sandstone, but soon after this, in one or two cases even just before its close, the struggle was renewed. "From the borders of Northumberland to the uplands of Galway, and from the slopes of the Lammermuir to Stirlingshire and thence across the estuary of the Clyde to Cantyre innumerable rents were opened and large bodies of lava and ashes were ejected." But there were important differences be-

tween the new outbursts and those which characterised the Lower Old Red Sandstone. The later materials were almost universally of a more basic character, basalts, or in one or two cases actually picrites. But yet more important is the character of the volcanoes. The earlier had a fairly determinate grouping, and must have formed masses commensurate with Vesuvius or even Etna; those later were smaller in size, especially towards the end, and more sporadic in distribution. During the earlier half of the time when the Carboniferous limestone was being deposited over England, a delta, or a succession of shallow lakes, occupied the central valley of Scotland; the discharges, except for their mineral character, more nearly resembled those of the Lower Old Red Sandstone, but afterwards they diminished in quantity and were more scattered. We can study them over many parts of the region mentioned above, but nowhere better than in Fifeshire and the basin of the Firth of Forth. Some of the sections which are exposed along the coast have been already described in an earlier chapter, so that it may suffice to refer to that and to the admirable descriptions and illustrations in Sir A. Geikie's great book. He divides them, as just intimated, into an earlier and a later group; the former, or "plateau eruptions," belonging to the close of the Upper Old Red Sandstone and to the Calciferous Sandstone of the Carboniferous period, when great lava-flows were ejected,[1] which now form broad table-

[1] Vents of this date can also be identified.—Sir A. Geikie, *ut supra*, chap. xxv.

lands or ranges of hills; the latter, or the puys, made when the discharges were sporadic and often small in extent. These appear not to have commenced until the other types of discharge were coming near to an end, and they continued through the rest of the Lower Carboniferous. In Ayrshire they seem to have remained in activity even to the beginning of the Coal Measures, but in other parts to have ceased before the epoch of the Millstone Grit. A second long period of repose intervenes, during which the Millstone Grit and Coal Measures were deposited, and then a new set of outbreaks occurred, connected probably with the earth movements which, as already mentioned, closed the Carboniferous period. To this second or Permian set of eruptions Sir A. Geikie refers many of the puy eruptions of the Fifeshire coast and of the basin of the Firth of Forth, such as, for instance, the cone-like summit of Arthur's Seat, the numerous necks between Elie and St. Monans, and the Rock and Spindle near St. Andrews. This reference, however, owing to the want of direct evidence, is more or less a matter of conjecture. But in Ayrshire some volcanic rocks occur, the age of which can be determined with greater precision. They form "a pear-shaped ring," about nine miles across at its greatest width, encircling red sandstones of Permian age and rising about the surrounding country, which is formed of Carboniferous deposits. These hills consist of lavas, in some cases obviously flows, with tuffs and other fragmental materials. Sir

A. Geikie thinks that, formerly, these Permian volcanoes were not confined to this comparatively restricted area, but extended over the lowlands of Ayrshire, down Nithsdale, and into the valley of the Carron, where also similar igneous rocks occur. True necks, filled with agglomerate, may be detected in many places, and are often in excellent preservation, giving rise to peculiar mounds, which are marked features in the scenery. "They are," he tells us, "on the whole smaller than those of the Carboniferous period. The largest of them in the Ayrshire and Nithsdale region do not exceed 4000 feet in longest diameter; the great majority are much less in size, while the smallest measure twenty yards, or even less." [1]

On the assumption that the volcanic outbreaks in Devonshire occurred, as was most probably the case, in the Permian and not in the Triassic period, the whole of the British Isles, like the adjacent parts of Europe, remained at rest throughout the Mesozoic era. But at the close of the large and widely extended depression during which the pure white limestone of the chalk, composed entirely or almost entirely of organic material, was deposited over at any rate nearly the whole of England, earth movements on a vast scale again took place, and a new outbreak of volcanic activity began. How far the two were connected it is impossible in the present state of our knowledge to determine. The effects of the former are most obvious in the south-east of Eng-

[1] *Ut supra*, vol. ii., p. 63.

land. Here the evidence indicates a renewal of the old post-Carboniferous movements, for the axes of the newer folds also trend, roughly speaking, from east to west. It further suggests that the undulations, which give a distinctive character to the scenery of South-eastern England, are connected with those mightier earth waves which formed the Alps and other mountain chains of Central Europe. But this has no direct relation to the region of volcanic disturbance. That lies far away to the north, and its principal scene was on or near the western coast of Scotland. It is indeed true that on the English side of the border, hints may be found of lines of strain more nearly parallel with those which have been mentioned ; but the great volcanic zone, at any rate in the British Isles, appears to have trended more nearly north and south. During this era, when, as it will be remembered, almost every country in the western half of Europe was the scene in one part or another of volcanic outbreaks, enormous quantities of materials were ejected along a zone extending at least from Antrim to Skye ; and a much larger region, in all probability, was more or less affected. This era of eruptions seems to have been a very long one, even in a geological sense, and to have ended, as is common, by passing through a puy stage. As these eruptions are comparatively recent, being probably contemporaneous, in part at least, with the volcanic hills of Auvergne and of the Eifel, we might have expected to find a comparatively easy task in deciphering the records of the rocks,

and to be enabled, in this part of the history, to speak with more than usual confidence. Such, however, is not the case. We are at once plunged into a sea of controversy. The chronological sequence of the materials, the modes of ejection, are alike matters of keen dispute, into which the limits at our disposal preclude us from entering. We shall content our-

FIG. 17. DIAGRAMMATIC SECTION OF SCUR OF EIGG.
The mass below is the older basalt; *c*, is an ancient river gravel; *p*, the remains of a flow of pitchstone that has descended the valley.

selves with stating such facts as are universally admitted, and with indicating the main points at issue.

All geologists agree that volcanic outbursts on a gigantic scale took place in this region during the Tertiary era. The basalt plateaux of Antrim, Mull, Skye, and others of the Western Isles, not to mention

the adjacent coast of Scotland, and the Red Hills of the two above-named islands, were formed by outbreaks in connection with the great line of eruptive action which, as will be shown in a later chapter, extends far away into Arctic regions. The dates when these outbreaks began and ended cannot be precisely determined. It was certainly later, as we can ascertain in Antrim and in Mull, than that when the very highest beds of the chalk were deposited; in other words, we may assign it without hesitation to the Tertiary era and with much probability to some part of the Eocene. It certainly continued for an immense time; for here, as in Auvergne, the basalt plateaux have been furrowed by deep valleys, which have themselves become the channels for lava streams of later date and different mineral composition.[1] Still the volcanic fires seem to have become extinct, the hearths cold, before the arrival of the Glacial epoch, and there are no such perfect puys anywhere in Scotland or Ireland as in Auvergne or even in the Eifel. The eruptions accordingly must have ceased, at the latest, during the Pliocene period. But farther than this we are unable to go. The volcanoes appear to have been mainly, if not wholly, subaerial; and the conditions in that case are generally unfavourable to the preservation of fossils, which alone can help us to anything like precision in determining our dates. The tuffs, indeed, which are intercalated with some of the basalts of Mull, con-

[1] See the description of the Scur of Eigg, Sir A. Geikie, *Quar. Jour. Geol. Soc.*, xxvii. (1871), p. 279. Professor Judd, *Id.*, xxx. (1874), p. 220.

tain the remains of plants; but fossil botany, in the present state of our knowledge, is not nearly so helpful for stratigraphical classification as palæontology; and these tuffs as yet have not furnished any relics of animals, not even a land-shell or an insect. The late Professor Heer referred the plants—first detected by the Duke of Argyll—to the Lower Miocene. Mr. Starkie Gardner has maintained that they are Eocene, and approximately contemporaneous with the Bournemouth Beds.[1] But whichever opinion we adopt, the difficulty is not yet ended. The authorities to whom we are indebted for the fullest description of these volcanic rocks, are directly at issue upon their order of succession. The ejected materials, if we put aside for a moment those of the puys concerning which no dispute has arisen, may be placed in two groups, the acid and the basic, the one consisting of rather fine-grained granitoid rocks,[2] with associated lavas and ashes of similar composition; the other of gabbros, dolerites, and basalts, with the usual fragmental associates of the last. This marked diversity of their mineral composition, together with other evidence, leads to the conclusion that the two groups are separated by a not inconsiderable interval of time. But which is the earlier—the acid lavas with their crystalline representatives, or the basic with theirs? Is the

[1] The plant-bearing beds to the west of the town are Lower Bagshot; those on the other side of Bracklesham age.

[2] The kind which petrologists designate by the meaningless and inaccurately applied name of granophyre. It indicates the deep-seated condition of the material of the acid lavas, as the gabbro and dolerite do that of the basic.

gabbro intrusive in the granite, or the granite in the gabbro? Professor Judd is confident that the acid rocks are the older; Sir A. Geikie is no less positive of the reverse. We abstain from an expression of opinion on a district which we have not visited for many years, and shelter ourselves under the old proverb about the disagreement of doctors. Perhaps some day a scientific jury will be empanelled to try this case in the Western Isles, but it may be contempt of court to venture tc anticipate their verdict.

This, however, is unfortunately not the only point of dispute, though the other is hardly of so much importance. That may be called the mode of the ancient Scotch eruptions. Professor Judd holds that the gabbro masses of Ardnamurchan Point, Rum, Mull, and Skye, such as for instance are seen in the Cuchullin Hills, represent the supply basins of great volcanoes, and that the sheets of basalt welled out from rifts in their flanks. These volcanoes were once far higher than Vesuvius, and fully rivalled Etna, for he estimates that the summit crater which once rose above the ruined masses of the Cuchullins could hardly have been less than 10,000 feet above sea-level, and may very well have been considerably more; while that which has vanished from Mull was, if anything, somewhat more elevated. Sir A. Geikie, however, does not admit the existence of these great central volcanoes, and believes that parallels for the lava sheets of the Western Isles and of Antrim must be sought in the fissure eruptions of Montana and Wyoming, and not in

the floods from Etna or Mauna Loa. The gabbro masses he regards, not as the broken foundations of an ancient volcanic mountain, but as approaching nearer to laccolites, as representing molten matter which had forced its way at a comparatively late stage in the history between the accumulated sheets of lava and the subjacent stratified rocks. Here, the thick covering of badly conducting material has caused it to cool slowly, and to become coarsely crystalline. On this question much may be said on both sides, for it is one where direct evidence cannot be easily obtained; probably geologists will incline to the one view or the other in accordance with their past experience and their natural temperament.

Though volcanic vents of Tertiary ages cannot be detected in England, it is highly probable that our country did not escape disturbance. The Cockfield and Cleveland dyke, which, as already mentioned, runs across Yorkshire for about sixty miles, cutting all the strata in succession from the Coal Measures to the Inferior Oolite, can hardly be assigned to any other than a Tertiary date, and is probably contemporaneous with some of the great flows in the Western Isles.[1] So also may be some other dykes in the north of England, and of course many dykes and some sills in Scotland itself, though here it is often hard to distinguish between Tertiary and Palæozoic basalts. How

[1] Mr. J. J. H. Teall, to whom we are indebted for an elaborate memoir on these north of England dykes, thinks the Armathwaite dyke cannot be separated from this, which would give a course of ninety miles. The rock is an augite-andesite rather than a true basalt.—*Quar. Jour. Geol. Soc.*, xl. (1884), p. 209.

far south the disturbances extended we cannot say; possibly, as already stated, to Staffordshire, and the phonolite of the Wolf Rock off the Cornish coast certainly has not a very ancient aspect. But there can be no reasonable doubt that volcanic action ceased in these islands well before the Great Ice age, and probably at an earlier date than in the Eifel or in Auvergne.

CHAPTER V

THE DISTRIBUTION OF VOLCANOES

IN the preceding chapter we have given a summary of the volcanic history of the British Islands. In the present one we shall add a few particulars concerning other regions.[1] In these it is impossible to trace the history so far back as in our own country, for in many cases information cannot be obtained, and in the others an attempt to enter into details would extend this volume beyond its due limits. But a knowledge of the general plan of the vents in a volcanic district and of the more obvious features in its later history, together with the nature of the products ejected, may have some value in theoretical investigations. Among other limits we must adopt that of time, and must thus pass over regions of fossil volcanoes; that is, wherever destruction has progressed so far that, as in our own islands, nothing remains which approaches to a perfect crater; we shall also touch but briefly on those in which an actual eruption is not known to have occurred in historic times.

A map of the earth on which the position of volcanic vents is marked shows at a glance that their

[1] The map at the end of the volume will give a general idea of the distribution of volcanoes on the earth's surface.

distribution can hardly be a matter of chance. The majority of them are in the neighbourhood of the ocean. They are often situated on islands: they are seldom at any great distance from the coasts of continents. Also they exhibit a more or less linear arrangement. Here and there, it is true, they seem to occur sporadically, after no definite law: but even in some of these cases closer study often shows that the irregularity is more apparent than real: for either they are ranged in two or three roughly parallel short lines, or extinct vents are found linking together those which are still active, thus proving that in past ages the chain of volcanoes was more complete than it is at the present day. These greater lines sometimes bifurcate; occasionally they are parallel, and in certain cases they appear to cross one another at high angles, forming a kind of "ganglion" at the point of intersection. A brief account of the geographical distribution of volcanic mountains, aided by the sketch map appended, may serve to bring out more clearly the rule already mentioned, and to show that the exceptions to it are comparatively few.

We will adopt, as far as may be, a continental grouping for the vents, and commence with Europe. Beginning at the north-west extremity we pass over our own island for the reason just given, but must not forget that its lavas are connected, as already described, through the Faroes (where also no craters remain) with the still active vents in Iceland. This island, though its area is about one third larger than

that of Scotland, appears to have been built up above the sea entirely by volcanic action. Fragmental materials are said to form an important part of the interior and highest part, but the hills of the east and west are for the most part basaltic lavas, some of the flows being very extensive. About twenty-seven volcanoes are known to have been active since the ninth century, when Iceland was first inhabited.[1] Of these Hecla is the most noted, an isolated summit rising to a height of about 5100 feet, some twenty miles from the south-west coast. Since the beginning of the eleventh century twenty-six eruptions have been recorded, several of which have been remarkable both for their duration and for their violence. One, which began in September, 1845, lasted for more than a year, and the ejected dust fell abundantly in the Orkneys, quite 500 miles away. Copious discharges of this material seem, indeed, to be rather characteristic of Icelandic eruptions. As a rule, however, lava-flows apparently dominate over fragmental materials, the major part of the island being sculptured out of an elevated plateau which they have built up; and the same remark applies to the Faroes, Franz Josef Land, and other islands bordering the deep basin of the Arctic Ocean ; it even holds good in the north-western zone of the British Isles and on the more distant western coast of Greenland. The ejected materials, especially in these great flows, are basalts, but in some

[1] Baring-Gould, *Iceland: Its Scenes and its Sagas* (1863), gives the total number of eruptions then recorded as eighty-six. (Introduction, p. xxiii.)

places, including Iceland itself, trachytes of various kinds, and even obsidians, have been discharged.[1] Here, also, as has been already stated, we have hot springs, geysers, and natural cauldrons of boiling mud, as near Krafla. Iceland is now the only active centre of a great volcanic province in connection with that broad causeway which once linked together the north-west of Europe and the north-east of America, and still separates the deeper basins of the Arctic and Atlantic Oceans.

Of the old volcanoes of Central France a very brief sketch will suffice, as some of their more characteristic features have already been noticed.[2] In Auvergne the earlier outbreaks were trachytic, and these sometimes built up rather lofty cones, such as that of which the Puy de Sancy and the Cantal are remnants. Large sheets of basalt were next discharged, and after a long interval, as already described, a number of minor vents were opened, the craters of which are still in many cases singularly perfect. The materials ejected by these are often basaltic, but they are rather variable in character, some of them ranking with the trachytes. Though, occasionally, traces of a linear arrangement may be detected, these vents are generally sporadic in distribution. Altogether a very large area of Central France, within a rudely triangular outline, the corners of which may

[1] As from Hrafntinnufjall, near Krafla. (Baring-Gould, *Iceland*, p. 213.) He speaks of the trachytic discharges being more recent than some of the basaltic.

[2] Pages 98–118.

be approximately indicated by Vichy, Montelimar on the Rhone, and the edge of the limestone region east of Cahors on the Lot, has been the scene of volcanic eruptions in later Tertiary, and perhaps locally in historic times.

Even extinct volcanoes are few in Portugal and Spain. In the former country some remains occur in the Sierra Caldeirão, in the extreme south of the kingdom; in the latter, near the coast, between Almeria and Carthagena, and in the province of Catalonia. The most perfect and important in either country, were first described by Sir Charles Lyell, who examined them in 1830. The vents lie on a tract about fourteen miles long from north to south, and six from east to west. As he says in a letter written at the time to his friend, Mr. Poulett Scrope,[1] "like those of the Vivarais [the volcanoes of Catalonia] are all, both cones and craters, subsequent to the existence of the actual hills and dales. . . . The cones, at least fourteen of them, mostly with craters, stand like Monpezat, and as perfect. . . . The currents flow down where the rivers would be if not displaced; but here, as in the Vivarais, deep sections have been cut through the lava by streams. . . . There are about fourteen, or perhaps twenty, points of eruption without craters." The materials mentioned are basaltic, and though the craters seem to be fairly perfect, Lyell expressly says, "there never was an eruption within the memory of man."

[1] *Life, Letters, and Journals*, vol. i., p. 283.

Proceeding next to Germany we find in the Eifel a number of volcanic vents, which, like those of Auvergne, are scattered, though yet more irregularly, over a triangular upland region, here consisting mostly of Palæozoic rocks, and which differ much in their state of preservation and in geological age. The date of the earliest outburst cannot be determined, but probably it was soon after the Eocene period; the latest seems to have occurred during the time when the mud called loess was deposited, and after the main valleys had been excavated down to their present level. The latter is proved by the deposits of volcanic ashes in the lower part of the Brohlthal and the lava-flows which, near its entrance, descend the flank of the Fornicher-kopf almost down to the level of the Rhine. The former limit may even bring us to Palæolithic times; but, as a rule, the craters in the Eifel are hardly so fresh-looking as the best preserved of those in Auvergne. The materials in the former are generally basalt, but phonolites occur in more than one region, while around the Laacher Sea and in the adjoining district, from the south-west round to the north-west, leucite is a common constituent. The lava-flows are seldom extensive and the craters rise to no great elevation, and in some cases, as already described, are now filled with water.

The Roderberg, which rises immediately on the left bank of the Rhine, about two miles south of Königswinter, to a height of some 400 feet above the river, may be regarded as an outlier of the Eifel volcanoes.

The crater, formed of basaltic scoria, is very perfect, and has some loess deposited on the flanks and interior, showing that this locality also was the scene of volcanic disturbances at the close of the Tertiary era. The great masses of basalt quarried near Unkel, and forming the columns of the Erpeler Ley, on the eastern bank of the river, are memorials of earlier episodes of eruption, and so are the well-known hills of the Siebengebirge; but, in these, activity must have ceased long before the eruption at the Roderberg, for, though fragmental materials occur, no crater remains. The hills here are masses of volcanic rock: sanidine-trachyte, as in the Drachenfels, andesite in the Wolkenberg, a fine-grained dolerite in the Löwenberg, and basalt in the Oelberg and other hills. The basic rocks appear to be the newer, and these distinctly predominate. This is also the case in the Westerwald, of which the Siebengebirge may be regarded as the north-western angle, and this leads into an extensive district where volcanic vents are scattered more or less sporadically. As the craters have perished I call attention to them only as indicating the extent of the ancient volcanic region in this part of Europe. Taking it as a whole it seems to consist of two intersecting bands, one running parallel with the Mosel and Lahn,—the Eifel and Westerwald,—the other extending down on the eastern flank of the Rhine valley, from the neighbourhood of Cassel almost to where that river forms the northern frontier of Switzerland. In the latter zone basalt is the usual rock, but varieties

containing nepheline are not uncommon, and in a few places phonolites occur, as in the small isolated masses near Höhgau to the north of Schaffhausen, and at the Kaiserstuhl, which rises about ten miles from Freiburg in Breisgau, out of the actual plain of the Rhine. It is noteworthy that the low hill by Limburg, about a league north of the latter mass, marks another and much smaller outbreak, which, however, is very different in chemical composition, for it consists of an unusually basic variety of basalt (limburgite). Though volcanic outbreaks occurred during the earlier Tertiary ages in Saxony and other parts of Germany, as well as in the Vicentin at the south-east of the Alpine chain, no craters remain. We can only say that the eruptive action which during the Permian period was so extensively manifested in Germany, as in the Thüringerwald, the Riesengebirge, and other districts to the south,[1] was again conspicuously displayed in the Teutonic regions. Basaltic cones, doubtless of Tertiary age, occur in north-eastern Bohemia at the foot of the Fichtelgebirge, from Egra to Parkstein, where they break through rocks of Keuper (Triassic) age, and are probably nearly coeval with the similar masses already mentioned in the middle Rhine district. In the Kammerbühl,[2] between the towns of Eger and Franzenbad (the structure of which about

[1] There were also many outbursts over a long zone of country in the Alps south of the existing watershed, and eastward from the valley of the Sesia. In the Italian Tyrol it was carried on into the Trias.

[2] Described and figured by Professor Judd (*Volcanoes*, chap. v.) See also for all this part of Europe his papers in *Geol. Mag.* (1876).

a century ago was a subject of much controversy), though the crater has perished, the plug of basalt by which the orifice has been closed is now exposed almost at the summit of the hill, which itself is a mass of scoria. In this part also of Bohemia, south of the Erzgebirge, on either side of Töplitz and Aussig, the Mittelgebirge range is formed by hills of basalt and phonolite. In these also, so far as I can ascertain, no craters exist, but the outbreaks are doubtless contemporaneous with some of those in the Rhine region. According to Boricky, to whom we are indebted for a careful study of the petrographical characters of these interesting rocks,[1] the oldest of them are basalts, forming sheets and streams of considerable extent, many of them containing nepheline abundantly, or even leucite. Through these the phonolites, for which this region is noted, have broken, apparently issuing in a pasty condition like some of the craterless masses in Auvergne. They now form elevated hills, as seems to be such a common habit with this rock. But later than both groups are some basaltic outbursts, generally of a rather exceptional character, certain of them, which approach andesites in composition, being unusually glassy. Professor de Lapparent states, on the authority of Professor Fouqué,[2] that the first of this group of outbursts is situated on a line running from north-east to south-west, and is linked to similar eruptive masses in Saxony, the Fichtelgebirge, the

[1] *Phonolithgesteinen Böhmens* (1873) and *Basaltgesteinen Böhmens* (1874).
[2] *Traité de Géologie*, book iii., Sec. 1, chap. iii., § 3.

Schwarzwald, and the Kaisersthul, while the direction of the second and third is at right angles to this line, and these eruptions are associated with centres of like nature in the Thüringerwald, Cassel, and Göttingen. Another broad volcanic belt borders the Carpathians on the inner side of their curve, through a considerable part of Hungary proper and the Siebenbürgen. Its vents were active in the Tertiary era, and ejected many varieties of trachytes as well as basalts. Discharges appear to have taken place, with intervening pauses, as already has been described, in the neighbourhood of Schemnitz, beginning in the upper part of the Eocene and lasting into the Pliocene. A few craters still remain in the Siebenbürgen, as near Tuschnad,[1] and the frequent presence of hot mineral springs shows that even now the solfataric stage is barely at an end. Trachytes in this region were first erupted, next came varieties of andesite, and these were followed by both rhyolites and felspar-basalts.

In quitting this part of Europe we may mention that the North German lowland (as might be expected), Scandinavia, and the whole of European Russia, except some slight instances in the extreme south, are free from either Tertiary or recent volcanic disturbances. But after crossing the Alps we find, as in the case of the Carpathians, that we come into a region which has been since the upheaval of the present mountain chain began, and in some places

[1] Daubeny, *Volcanoes*, chap. vi., on the authority of Dr. Boué.

still continues to be, the scene of volcanic discharges. Nearest to the chain are the Euganean hills, lying to the south-west of Padua. This picturesque range, the highest summit of which rises to a height of 1700 feet above sea-level, consists of various trachytic [1] rocks; but as the eruption probably ceased at an early date their craters have perished, and they are now no more than the wrecks of volcanoes. But as we travel southward we come, after crossing the watershed of the Apennines, upon the great volcanic region of Central and Southern Italy, to which we have already more than once referred. Scoria, tuffs, and lava streams, craters with and without lakes, occur at intervals from the border of Tuscany through the Roman States into Campania, while the Ponza Islands to the west of Naples and the Lipari group off the Calabrian and Sicilian coasts are almost wholly volcanic in origin. The eruptions in this Italian region began at a later date than those mentioned above, and here a few vents still continue active. Not the least remarkable of its characteristics is the existence of two contiguous petrographical provinces, in one of which also quite extreme varieties of igneous rock have been contemporaneously ejected from almost adjacent vents. Leucite is distinctive of the lavas of the mainland, with the exception of those in the Phlegræan Fields; while this mineral does not occur in either of the two island groups, the rocks of which are sometimes actually pitchstone and obsidian,

[1] Rhyolites and sanidine-trachytes.

with various trachytes and sometimes basalts.[1] Of the former group Vesuvius, already described, is the still active centre, and to it belong the crater-lakes mentioned in a preceding chapter. The seven hills of Rome are carved out of volcanic tuffs, containing leucite,[2] to which, however, an earlier date must be assigned than to the craters of the Alban hills[3]; for although in a geological sense these eruptive products are comparatively modern, the most ancient not quite going back to the Pliocene period, the age of the earlier among them would seem vast in comparison with historical chronology. In one or two parts of this region the oldest ejections are said to be trachytic, but very soon the discharge of leucitic rocks commenced, and has continued in the case of Vesuvius to the present day.[4] Passing to the other province, the Ponza Isles are now in a very shattered condition. These, as Professor Judd remarks,[5] are situated on a line passing from Monte Vultur in Apulia through Vesuvius and Monte Epomeo in Ischia. It must,

[1] That is to say, they contain 15 to 20 per cent. more silica than the Vesuvian lavas, but perhaps only half as much potash.

[2] Some of the tuffs in the vicinity of Rome are referred by Lanciani to the Bronze Age or to the Neolithic.—*Geol. Mag.* (1877), p. 439.

[3] Lanciani, *Ancient Rome* (1897), states that pottery has been found beneath beds of volcanic ash near the Lago d'Albano. This he refers to the Bronze Age, which he supposes was not quite ended when Rome was founded (B. C. 754). He quotes Livy as authority for traditions of eruption, *e. g.*, "Ter Monte Albano lapidibus fluit."

[4] *Amer. Jour. Geol.*, H. S. Washington, on "Lago di Bolsena," iv., p. 541. Still, an augite-andesite discharge is mentioned as a local occurrence and of late date.

[5] In an excellent account in which references to older authors are given. —*Geol. Mag.* (1875), p. 298.

however, be remembered that the rocks in them and the last named differ much from those ejected in the other two localities. The Ponza Isles, which are almost wholly composed of volcanic materials, consist of pumice and extremely acid lavas; the latter in some cases, as was long ago shown in Scrope's classic paper,[1] being actual obsidians or pitchstones. The islands form two groups about twenty miles apart, that nearer to the mainland being probably two fragments of a large cone, the other consisting of volcanic masses, the lower parts of which are distinctly older than the upper. An isolated rock in the interval between these groups no doubt marks the site of another vent; but no perfect craters remain, and no eruptions have occurred in historic times.

In the Lipari Islands, as already stated, eruptive activity is still displayed; but there also we find a remarkable instance of the practically simultaneous ejections of materials differing greatly in chemical composition, from vents which are comparatively near, Vulcano and Lipari discharging rhyolites, but Stromboli, basalts.[2] Yet between the second and third islands the distance is only about twenty-two miles, and half-way between them is a cluster of small islands, which, according to Professor Judd, marks the site of a shattered cone. In these the rocks are

[1] *Trans. Geol. Soc.*, ser. ii., p. 195. See also Judd, *Geol. Mag.* (1875), p. 298. According to the latter the Ponza lavas much resemble those of the Euganean hills and of Hungary.

[2] See Judd, *Geol. Mag.* (1875), p. i. *et seq.* Backstrom, *Geol. Fören. Stockh. Förh.*, xviii. (1896), p. 155, states that leucite has also been found.

intermediate in composition between those of Lipari and Stromboli, while in other islands the materials first ejected were of the same character. Thus the fissures from which these vents proceed appear to have at first opened into a common source, and afterwards to have drawn upon the extreme types, of which it may be regarded as a mixture.

The Phlegræan Fields, with Ischia and other adjacent islands, form a group of volcanoes rather peculiar in form and exhibiting various stages of ruin. A few eruptions have occurred here in historic times, but, so far as we can infer, the volcanic forces are gradually becoming extinct. Ischia is practically formed by a single volcanic cone, Monte Epomeo, which has been breached on the southern side by the sea. It is spotted by smaller parasitic craters, and lava flowed in the year 1301 from a point on its eastern margin. The severe earthquakes of 1881 and 1883 showed that the buried Titan is slumbering, but not yet dead. A stream of lava was discharged in 1198 from the Solfatara on the mainland, and here also the ejected steam and the pools of boiling mud show that it is still alive, while the eruption of Monte Nuovo in 1538 has been already described. The craters of this region, in general, are broad in comparison with their height, so that a map of the Phlegræan Fields resembles one of part of the surface of the moon, though on a very much smaller scale.[1]

[1] The mean diameter of the ten largest lunar craters is 275 miles, but there are also many no larger than the terrestrial.—G. K. Gilbert, *Amer. Jour. Geol.*, iv., 241.

But the district as a whole shows more than one phase of volcanic history. In the maps accompanying Mr. R. T. Günther's recent description of the district[1] the relation of the older and newer craters is clearly shown, the former being on much the larger scale. In one of them, marked by the range of Camaldoli, extending from St. Elmo to Capo de Monte, a side of which has been destroyed by the sea, part of the city of Naples is situated, the remainder lying in a second broken crater, which runs from Castello del Ovo to the ridge of Posilippo. Astroni and the Solfatara are both modern craters, which have been formed on the margin of one much more ancient, and about three miles in width. The far-famed lake of Avernus is an illustration of a crater-lake, and of the way in which the point of discharge sometimes is shifted along a line of fissure,[2] for it has partly destroyed or buried one half of an older crater, Monte Grillo by name. According to Mr. Günther these vents of the Phlegræan Fields occupy a crescentic area, which curves round the Bay of Puzzuoli, the more modern lying nearer to the sea, and thus "indicating a gradual march of volcanic vents along lines radiating towards the centre of that bay." We must not forget that this region also affords another instance of the comparatively simultaneous ejection of very different materials. Those from the Phlegræan Fields are varieties of trachyte, while Vesuvius, as has been already stated, ejects leucitic lavas,

[1] *The Geographical Journal*, vol. x. (1897), pp. 412, 471.

[2] The Puy du Pariou in Auvergne, as already mentioned, affords a parallel case.

like the other mainland volcanoes; but here also the very first eruptions of all were trachytic. In Italy one volcano only is found on the eastern side of the Apennines, the vents evidently occurring (in accordance with the usual law) where the mountains descend most steeply to the sea. This is Monte Vultur,[1] an insulated, extinct volcano, lying about half-way between Naples and Bari. It is conical in form, rising to a height of about 4100 feet above the sea, and measuring some twenty miles round at its base. Thus it covers a larger area than Vesuvius. The Lipari Islands seem to form a connecting link between the Neapolitan district and Etna, and thus suggest the existence of a line of weakness in the earth's crust, running slightly to the east of south. This volcano is unquestionably on the grandest scale of any in Europe, for it rises from comparatively low land to a height of full 10,800 feet above the sea, and stands on a base ninety miles in circumference, from which it slopes steadily upwards to its summit crater, the walls of which are between two and three miles in circumference. The generally uniform contour of its cone is only interrupted on the eastern side by the huge chasm of the Val del Bove, already mentioned, and by many small subsidiary cones, one of which, the Monti Rossi, a double crater thrown up in the eruption of 1669, attains a height of about 450 feet. So frequent

[1] On the slopes of which, according to Horace's own story, he one day fell asleep when a child, and the doves covered him with green leaves like another babe in the wood.—*Odes*, iii., 4, 9.

are these parasitic cones that a model of Etna on a rather small scale looks as if the mountain was sufferfering from a bad attack of pimples. This volcano surpasses even Vesuvius in its bad reputation for destructive eruptions.

To quote only a few instances: In 1169, Catania was partly destroyed, with a loss, it is said, of 15,000 lives; in 1669, the mountain flank was rent by a fissure twelve miles long, from which lava and steam were discharged; in 1755, a great flood of water streamed from the Val del Bove, while during the long eruption in 1852 and part of the following year a torrent of lava was ejected which was six miles long and in places two miles broad. The eruption of 1865[1] also was a long and violent one, the principal discharges taking place from a subsidiary crater near the summit. On the whole, more than one hundred eruptions are on record in the history of the mountain, and this is not likely to be complete. Three eruptions, according to Thucydides, took place after Sicily had been colonised by the Greeks and before the Peloponnesian war.[2] Etna ejects basalt, but leucite has been observed; and among the minor peculiarities is one which proves that volcanic ash or the crust of a lava stream is a very bad conductor of heat, for near the Casa Inglese, at a height of about 9600 feet above the sea, Sir Charles Lyell, in 1828, found a mass of ice,

[1] Rodwell, *Etna and its Eruptions*, p. 109.

[2] See Daubeny, *Volcanoes*, chap. xv., for this and other quotations from classic authors.

which still remained at the time of his second visit, thirty years afterwards. It was covered by about ten feet of volcanic sand, over which a lava stream had flowed.[1] But the evidence of weakness in the earth's crust does not end with Etna. The branch fissure already mentioned in the Lipari Islands probably runs to Ustica, where are craters of basaltic material invaded by the sea,[2] and another one in a W.S.W. direction may extend by Graham Island to Pantellaria, between Sicily and the nearest part of Africa, where there appears to be a large ruined crater of trachytic materials, some, as is the case at Vulcano, being very glassy.[3]

In the Grecian Archipelago the active vents and shattered crater-ring of Santorin have already been described, so it may suffice to say that the rocks here are varieties of trachyte, both obsidian and pumice being mentioned among them. In Milo, one of the group, the rock is said to have been silicified, and thus converted into an impure jasper. This is no doubt a result of solfataric action, the felspathic constituents of the rock being slowly dissolved away by the action of hot water, and replaced by silica which has been brought by the latter in solution. This process has occurred elsewhere, as, for instance, in the millstone trachyte of Hungary; and in our own country the very ancient lavas of Roche Castle, near St.

[1] *Principles of Geology*, chap. xxvi.
[2] Daubeny, *loc cit.*, chap. xiv.
[3] *Ut supra*, chap. xv.

Davids, have undergone the same treatment.[1] The other islands of the Greek Archipelago show no sign of volcanic action, at any rate of recent date, with the exception of Nisyros, off Cape Methana, in the north-east of the Peloponnese, and on the adjoining mainland. The former is described as the ruin of an ancient crater[2]; in the neighbourhood of the latter are hills of trachyte, the most elevated rising more than 2200 feet above sea-level. Here, if Strabo be rightly interpreted, eruptive action had not quite ceased in his day, but at present some hot springs are the only signs of internal disturbance. The volcanoes of the Greek Archipelago cannot be immediately connected with those of the Italian peninsula, because one of the great basins into which the Mediterranean is divided lies between them. But it is a little remarkable that the Santorin group rises on the opposite side of a well-marked depression which lies immediately to the north of Crete, almost as if it were a mould in which the island had been cast.

In Western Asia, the district to the south of the Caucasus, lying between the Black and the Caspian Seas, appears to form a knot-point, from which zones of volcanic disturbances branch out in three directions. Westwards from the centre (the plateau region tra-

[1] They are probably slightly older than the Cambrian period. The author was one of the first to examine a specimen of a very compact form from another locality (Treffgarn), and was completely baffled by it. The key to its true nature was afforded by a specimen from Roche Castle, in which the original felspar and a fluidal structure could be traced.

[2] Daubeny, *Volcanoes*, chap. xviii.

versed by the frontier of Russia and Turkey in Asia) sporadic volcanoes, all extinct and mostly in ruins, extend over the highlands of Anatolia. The most important of these is Ergish-dagh, the ancient Argæus, in the south-east corner of Angora. This terminates in two craters and attains an elevation of 13,100 feet, or more than 10,000 feet above the general surface of the plateau. Whether this zone may be carried so far as to reach the Mediterranean and to include the volcanic group of Santorin, is difficult to ascertain; but the existence of a line of weakness extending from the above-named centre in a southerly direction seems to be more clearly marked. It runs along the highlands separating the Syrian desert from the Mediterranean, being best marked on the eastern side of the upper waters of the Jordan.[1] Here, between the Hauran and the oasis of Damascus, in the eastern Trachonitis, are many lava-flows and craters, all apparently basaltic. They seem to be scattered promiscuously, but are said to be ranged along three fairly distinct parallel lines trending slightly north and south. West of the Jordan only one or two small isolated, extinct volcanoes can be found, and these are wanting in the more southern part of the Jordan valley. But there is more than one volcanic district on the western side of Arabia, for this is the character of certain generally desolate tracts, locally called Harra. They occur chiefly in the northern part of that coun-

[1] Not improbably there may be some connection between it and the fault, or faults, which have determined the Jordan valley.

try, and Mr. C. M. Doughty, who formerly travelled there at not a little personal risk, describes [1] in one of them cones, craters, and flows of basalt of considerable size, extending at intervals down the western side of Arabia to about the latitude of Jiddah. Another volcanic region is found near the Strait of Bab-el-Mandeb, Aden itself lying in an ancient and ruined crater, and others extending from Oman across the Hormus Strait into Persia.

It is, however, in the central region itself and in its eastward extension that the most important indications of comparatively recent volcanic action are to be found. The Armenian highland, using the word in a somewhat wide sense, has been the scene in olden time of great volcanic activity, and appears to be, as already stated, the centre from which those three lines of disturbance have radiated. Enormous masses of volcanic rocks, the discharge of which probably began in Pliocene times, were ejected over a large tract south of a line running from Poti, through Tiflis, along the valley of the Kur. Extinct cones are dotted here and there over the series of elevated plateaux, which are divided up among Turkish, Russian, and Persian territory; often they are not very conspicuous, but occasionally they rise to a great height. Centrally situated and dominating over all the others is the historic Ararat. It rises from a plateau varying from 2500 to 3000 feet above sea-level, its base being about twenty-five miles long by half the breadth,

[1] *Proc. Roy. Geo. Soc.* (1884), p. 382.

and is linked on the north-west to a range of volcanic mountains of much less elevation, the principal cone, or Great Ararat, attaining an elevation of 16,969 feet; the lower, Little Ararat, of 12,840 feet. Both are built up by scoria and lava, but neither retains any trace of a crater,[1] though as the snow lies thick on the highest peak this may have filled up the hollow, and even raised a mound above it. The rocks which have been collected on Ararat are varieties of andesite.[2]

Another remarkable crater with a double name is described by Abich, by whom it was examined. Palandökan and Jarlydagh together form a huge crater, about six miles in diameter, the wall of which is breached by a valley called Dagyrman-Darassi. The more superficial structure of the districts round is shown by other valleys; the rocks are generally volcanic, though those of which the plateau itself consists must be near at hand. The name Palandökan is applied to a summit on the eastern side of the crater and that of Jarlydagh to the highest point of the western. The wall of the crater apparently consists of varieties of andesite (scoria and lava), and this is the dominant rock in the surrounding district, where, however, other kinds occur, some of them having a high silica percentage and a glassy habit. In

[1] The great chasm on the north-east side of Ararat, 9000 feet deep, and surrounded by enormous precipices, seems not to be a crater, though it may have been formed like the Val del Bove on Etna.

[2] They are described by Abich in his great work, *Geologie des armenischen Hochlandes*, and a collection made a few years since by Mr. Lynch (who reached the summit) has been examined by the author, an account of which will be published in due course.

fact, the ejected materials seem to range from varieties of quartz-trachyte even to basalt. This great crater exhibits one peculiarity, that part of its bed is formed, not of scoria or lava, but by the rocks which belong to the fundamental mass of the Tauric chain. Abich states that limestones, more or less metamorphosed, alabaster, serpentine, and various green schistose rocks, probably igneous in origin, occur on its floor, which is about 7700 feet above sea-level. It is, therefore, evidently a crater formed very much after the type of some of the "maars" in the Eifel, though on a much more gigantic scale.[1] He remarks that Palandökan, like Ararat, lies on the volcanic axis of the Old World. Bingoldagh, another large crater, lies to the south of the last described. This is about three miles in diameter; the inner walls are steep, but the slope of the outer cone is gentle, varying from eight to ten degrees; the highest point apparently is about 12,087 feet, so that it approaches more nearly than the other to one of the ordinary type. No record exists of eruptions from either of these vents, and the Armenian volcanoes appear generally to have been quiescent in historic times. If, however, we can trust an Armenian authority quoted by Abich,[2] an eruption occurred from Mamrut,

[1] Abich quotes it as an instance of a crater of elevation, after Von Buch's hypothesis (see Chapter VI.), but there is no valid reason for adopting that explanation.

[2] *Geologie des armenischen Hochlandes*, p. 439. I am indebted to F. Oswald, Esq., B.Sc., who has recently been carefully through Abich's work, for this extract and a summary of that geologist's remarks on the two last-named craters.

now called Sipandagh, near Lake Van, in the year 1441. The passage runs thus: "In this year a great sign came to pass, for the mountain called Mamrut, which lies between Chlath and Bogesch, suddenly began to thunder like a violent thunder-storm, setting the whole land in fear and horror, for it could be seen that the mountain split asunder wide enough to hold a town, and from out of this fissure flames shot up shrouded in the darkest smoke of so fetid an odour that men fell ill from this deadly smell. From the dreadful flames glowing rocks of enormous size were hurled heavenwards, accompanied by peals of thunder. All this was clearly seen by men in other provinces." Abich[1] also refers to a passage in the works of St. Ephrem, the Syrian, written about 340 A.D., mentioning not only earthquakes, but also "fire and much smoke in the mountains of Armenia." On the northern part of this great plateau, which can be traced so far across the continent of Asia, the mountain chain of the Caucasus, between the Black and the Caspian Seas, rises like a frontier wall. Its bold and lofty peaks consist mainly, like those in the Alps, of crystalline rocks, probably of more than one origin ; but two of them are indubitably volcanic, and though the presence of a crater is doubtful, their position is sufficiently exceptional to call for a little more than a passing mention, for they occur, not on the flanks, but, what is less frequent, on the actual crest of the

[1] *Loc. cit.*, p. 444.

chain. Of these two summits the lower one, Kasbek (16,546 feet), is overtopped by five of the crystalline peaks, and it no longer retains any signs of a crater. But with Elbruz, the monarch of the whole chain, the case appears to be different.[1] "It has the regular outline of a typical volcano. Its characteristic peculiarity is that it culminates in two comparatively small cones of nearly equal height,[2] separated by a gap some 1500 feet in depth, and 17,000 feet above the sea-level. Each of these cones preserves the features of a crater in a horseshoe ridge, broken down on one side, and enclosing a shallow snow-filled basin." It has been suggested that the two may have formed part of a huge terminal crater, and when the mountain is regarded from the south-east this idea seems plausible; but Mr. Freshfield is unable to agree with it. In any case, however, Elbruz may be reckoned among those which retain relics of their craters. The rocks appear to be largely lavas, and that of the western summit is a hornblende andesite,[3] which I believe is also dominant on the mountain.

The eastern extension is marked by the Persian volcanoes south of the Caspian. Of these the most important is Demavend, which rises to a height of nearly 18,000 feet, the plateau of sedimentary rocks

[1] D. W. Freshfield, *The Exploration of the Caucasus*, vol. i., p. 31.

[2] 18,470 feet and 18,347 feet.

[3] A specimen (Pl. VII., fig. 4) from the highest rocks traversed on the western summit by Mr. Horace Walker, who was one of the party that first scaled it, and given to me by him, is described in *Proc. Roy. Soc.*, xlii., p. 324. That of Kasbek, according to Mr. Freshfield, is much the same.

at the base being about one half of that elevation;[1] the summit crater is about a thousand paces in diameter, and, beyond an odour of sulphur, the volcano now shows no sign of activity. Two or three large extinct volcanoes occur in the direction of the western frontier of Baluchistan, the Kuh-i-Naushada being the highest, probably exceeding 12,000 feet; and the Kuberku range, with some extensions to the south-east, suggests, it is said, a possible connection between these two rather widely separated volcanic districts. Volcanoes, as a rule, are absent from the great mountain chains of Central Asia. They have been asserted to occur in the Thian Shan, and the lists of such are given by both Humboldt and Ritter; but several of these have been examined of late years by Russian travellers, who in all cases have given their verdict in the negative. Koulkok, for instance, near Issikul, was ascertained by Séméno not to be volcanic; and the Solfatara of Katou, in the Ili valley, has proved to be nothing more than some beds of coal which had become ignited.[2] At present the existence of volcanoes, even extinct, in or near this mountain chain, if it has not been actually disproved, in every case is extremely dubious. Some few craters, however, appear to occur on the plateau of Thibet,

[1] The heights assigned vary much. Dr. Sven Hedin, who ascended the mountain in 1890, makes it 17,930 feet.

[2] See the summary in Saint-Martin and Rousselet, *Dict. Geog. Univ.*, *s. v.* "Thian-shan." Katou, accordingly, is in some respects a parallel with the case in Ringstead Bay, where the bituminous Kimmeridge clay was ignited by spontaneous combustion.

between the Lob-nor and the Kuen-lun chain, where Prince Henry of Orleans and M. Bonvalot mention extinct craters; and two such craters are described by M. Klemenz[1] as occurring in the valleys of the Sulein-gol and Kitschigein-gol, in the Khangai mountains, upon the northern side of the desert of Gobi. One of them is perfect, and measures about 360 paces in diameter; the other is breached on the northern side; the materials, scoria and lava, are basaltic. Von Richthofen[2] enumerates other parts of the great Chinese Empire in which volcanic rocks of Tertiary and post-Tertiary age occur, but the information at his disposal was not always precise; and, though here and there comparatively recent outbreaks may have occurred, the inland of China at the present day seems to be free from active craters.[3] In Korea, however, though no cone is now active, some volcanoes of recent date exist. The most important is Pay-tau-shen, near the Manchurian frontier. It terminates in a crater six or seven miles in circumference, now occupied by a lake, which has a place in some of the native legends. In the south of Korea, Quelpart and other neighbouring islands are also volcanic, retaining craters more or less ruined; but here we are approaching the great band of volcanic islands which sweeps round the eastern coast of Asia, and of which Japan forms a part, so that we

[1] *Russ. Geog. Soc.* (1897), p. 457.

[2] *China*, vol. ii., chap. xiv., § 16.

[3] Solfataras are said to be numerous in the province of Chañ-si.—Saint-Martin and Rousselet, *ut supra*, *s. v.* Chine.

turn back to complete our remarks on the mainland. Of this, Hindustan and the Indo-Chinese region alone remain. In India, the huge basaltic lava-flows of the Deccan have lost many craters with which they may have been formerly associated. Without the limits of the peninsula the mud volcanoes of Ramri, on the Arakan coast, the extinct craters of Popah in Burmah, and of Han-shuen-shan in Yunnen, besides the volcanic Andaman Islands, still indicate in all probability a northerly extension of the great volcanic line which passes through the Malayan Islands. Barren Island, one of the Andamans, consists of an ancient crater over a mile in diameter, invaded by the sea, from the middle of which a central cone rises to the height of over a thousand feet.

From the Andaman Islands already mentioned we pass through the Nicobar, in which are no active volcanoes, but apparently one or two ruined craters,[1] to Sumatra. This is united to Java and Borneo by a submarine plateau, the depth over which does not exceed about twenty-five fathoms, so that the group is as closely related as England and France. Volcanoes exist in all three of these great islands. In Sumatra, according to Reclus,[2] there are sixty-six, some of which rise to a considerable elevation. Of these Selawa Djanten, towards the western end, though

[1] Saint-Martin and Rousselet, *ut supra*, *s. v.* Nicobar.

[2] *Géographie Universelle*, *s. v.* Sumatra. See also Saint-Martin and Rousselet, *ut supra*, *s. v.* Sumatra.

only about 5663 feet high, is a striking object from its comparative isolation, and there are other craters of less elevation in the neighbourhood. Farther east are several in the main chain now in the solfataric stage. In the volcanic range of Merapi, Manindjoe is a great crater-lake, and Moro Api, with its crown of three cones, rising to a height of 9344 feet, gives its name to the district in which it plays the part of Ararat,[1] and is noted for its eruptions. Farther east Kaba is constantly exhaling steam, and in 1875 was in active eruption. Dempo, which is nearly twice as high, for it rises to 10,400 feet, is constantly in activity, and Korintji, which overtops it by full 1700 feet, is almost always emitting steam. Towards the eastern end of Sumatra two lines of weakness must unite, or more probably a great fissure, which has extended even from New Guinea, bifurcates at this point, the branch which has been followed being a continuation of the main line; the other fork striking up in a north-easterly direction towards Borneo, in which island, however, only extinct craters remain, none appearing to be in activity. The intermediate islands of Banca and Billiton are also free from volcanoes, being apparently without craters. The lavas of Sumatra are said to be andesites and probably basalts.

Turning back to the line already followed we pass to the Strait of Sunda, between Sumatra and Java, with the noted island of Krakatoa, already described,[2] and come to Java itself. Here are many volcanoes

[1] There is a similar flood-legend attached to it.

[2] Page 20.

which rise from a platform of sedimentary rock. Junghuhn[1] states that they are about forty-five in number, and that those in the western part of the islands are linked in groups of three or four, not along the main axis of the island, which is almost east and west, but transversely to it, and parallel with that of Sumatra, or roughly from north-west to south-east, while in the latter the reverse takes place, and the short volcanic links are parallel with the axis of Java. In the latter island the volcanoes are not continuous, but form groups some thirty miles apart. On the whole they are on a rather larger scale than in Sumatra, though no single one rises quite so high as Korintji. At the western end of the island, to the south of Batavia, Salak (7267 feet) in the year 1699 discharged great quantities of fine ash and water from its large central crater, which produced huge flows of mud and quite choked up its valleys, and though since then it has been at rest, fumaroles exist in the western part of the cone. Farther east Gedâh ejects ashes and steam, while its somewhat more lofty neighbour, Mandala Wangi (9915 feet), is in the solfataric stage. The latter rises on the eastern edge of the huge crater of Panggerano—more than seven miles in circumference and about a thousand feet deep; and there are others in the district, which, however, seem only to emit steam or acid vapour. Within the broken crater-ring of Papandayang—the Forge—are boiling pools of

[1] Reclus, *Géographie universelle*, *s. v.* Java. See also Saint-Martin and Rousselet, *ut supra*.

mud and springs of hot water, both sometimes spouting up, the continual noise being the origin of the name. A formidable eruption occurred in 1772, but no precise account of it has been given.

Goentoer, in the northern part of the same group, has the reputation of being the most active volcano in Java, for its eruptions are frequent, and from summit to base, over 7300 feet, it is a bare cone of scoria. Junghuhn estimates that in one of the more violent paroxysms it discharged more than ten million tons of fine ashes. These were shot up to a height of nearly two miles, where they floated away as a dark cloud through the air and came down on the country as a rain of dust. Galoongoon, which is about the same height, is less frequently in action, but an eruption in the year 1822 is reckoned among the most terrible that have occurred in Java. There were two special explosive episodes, one by day, the other by night, and on each occasion the hail of ashes and of larger stones was accompanied by torrents of mud, which proved terribly destructive, for in places it lay fifty feet deep and ruined the vegetation to a distance of more than twelve miles away. Basalt is named among the lavas of this neighbourhood. The Guevo Upas, already mentioned, is only a depression of moderate size in this district among some craters on the plateau of Dieng, one of which, Prahoe, now about 8300 feet above sea-level, is probably the basal remnant of a much more lofty cone. Fumaroles and hot springs are not infrequent, but unless changes have

taken place of late years the legend of the upas tree rests upon a comparatively small basis of fact. The mephitic vapours emitted by Padjalan, a crater nearer to the last-named group, are, however, more formidable, for Junghuhn states that he saw the bodies of even tigers and rhinoceroses lying on its bed.

Towards the eastern end of Java the crater of Keloet (nearly 5700 feet) usually contains a lake; but it has more than once discharged torrents of mud, and a great eruption occurred in 1848, the noise of which was heard even in the Celebes. A still wider crater is Tengjer, the largest in Java, for it is over fifteen miles in circumference. This probably is the basal wreck of a more lofty cone; on its floor are subsidiary craters, the principal one being sometimes active. It is very probably an illustration, though on a larger scale, of the phase through which Vesuvius passed between the great eruption in the first century of the present era and that of 1631. In the neighbourhood of it is Semerou, the highest volcano in Java, for its summit is nearly 12,050 feet above sea-level. It is constantly discharging steam and ash, but gave vent in 1885 to a lava-flow of considerable size, a rather unusual feature among the volcanoes of Java, for as a rule they only eject fragmental materials.[1]

The eruptive belt of Java is continued eastward by Bali and by Lombok, wherein are several extinct craters, with others in occasional activity, the most elevated being nearly 10,000 feet high. The same is true

[1] Obsidian and pumice are mentioned among its products.

of Sumbawa, where there are said to be twenty-two craters in all; but only one of these calls for any special notice, that is the crater of Timboro. This, one night in April, 1815, was the scene of an eruption almost as violent as that of Krakatoa, with the exception that from its position there was no such formidable disturbance of the sea. For several days explosion followed explosion, the air was black with the ejected dust, and the darkness was only illuminated by repeated flashes of lightning; the ashes were carried for long distances, especially towards the west; they floated in huge banks on the sea, and buried a large amount of land, with most disastrous results. Forests were destroyed, canals blocked, flocks and herds killed, and it is thought, directly or indirectly, perhaps even a hundred thousand persons perished.

The Javan line is continued from Sumbawa by Sangeang, another Stromboli, through the Flores Islands to Timor, in which the existence of volcanoes has been doubted; there must, however, be a very few, for one in the western part of the island is said to have been in eruption in 1856 and in the following year; there are also some mud volcanoes, but nothing calling for special mention. Timorlaut, in which is one extinct volcano, Laibobar, on the western coast, prolongs the above-mentioned line towards the southern part of New Guinea. In this great and mountainous island, some half-dozen times as large as England, no active volcanoes are known, though in the eastern part extinct craters exist, both in the

Finisterre mountains (11,500 feet) of German New Guinea, and on the spurs of the Owen Stanley range in the extreme east of the British territory.

This great insular mass, composed largely of crystalline or of rather ancient sedimentary rocks, seems to form a solid central block, from which the lines of fissure radiate, so that here we turn back from the scattered island groups of the Pacific to follow the course of that northern branch which, as already mentioned, sweeps in a series of crescentic curves along, but at a considerable distance from, the coast of the Asiatic continent. It is not, however, very easy to fix the precise direction of the lines of weakness which are indicated by volcanic discharges. Possibly one, the less important, runs up through Borneo and on the west side of the basin of the Sulu Sea to the northern part of the Philippine group, for a few extinct craters occur in Borneo, and perhaps yet farther north. But a better marked line can be traced, starting from nearer to the Flores Islands, through Celebes to the southern end of the Philippine archipelago. Along this also volcanoes are not numerous, but in the curving northern peninsula of Celebes there are two groups of cones. In one, the nearer to Borneo, Sapoetan has been in eruption during the present century, while hot springs and mud volcanoes occur in the district; in the other, at the extreme eastern end of the peninsula, the memory of eruptions is preserved by tradition. Basalt seems to be rather abundant. But in the islands linking Celebes with

the Philippines active craters occur, and one of these, Api by name, caused serious disasters in 1711, in 1812, and again in 1856. It is possible that another line of weakness extending from Celebes, north of the Banda Sea, towards the Charles Louis Mountains in New Guinea, may be indicated by Amboyna, for, according to Wallace,[1] a volcano on the west side of that island has been active half a dozen times in little more than two centuries, the last eruption on record occurring in 1824.

But the archipelago of the Moluccas, more especially in its northern part, certainly indicates a region where the earth's crust must be a good deal fissured. Among the craters from which eruptions have taken place in modern times may be named Makjan, the cone of which was truncated and eviscerated during an eruption in 1646, and from which enormous quantities of ash were discharged in 1862 ; also Motir, Tidore, Ternate (mentioned by Camoens), which emitted lava twenty-four times between the beginning of the century and 1862, and smoke always issues from the seven craters in which it terminates.

The volcanic axis of the Little Moluccas when prolonged skirts the coast of Halmahera, an island as irregular in form as Celebes itself, on which are some volcanoes, that of Tolo being apparently the most active, as well as some crater-lakes. One called Morotai ejects trachyte. Small volcanic islands rise from the submarine plateau which parts the basin of

[1] *Malay Archipelago*, chap. xx.

the Celebes Sea from the open Pacific, and these lead up to the Philippines, in which are cones both active and extinct, lying apparently along the axis of the islands themselves. The following may be noticed in passing: Apó, the highest, rises to full 10,300 feet above the sea; a cone in the islet of Camiguin has covered the surrounding district with ashes and augmented its own height; Bulusan, in the extreme south of Luzon, and the loftiest in that island, is comparable with Vesuvius, for its cone is half encircled with a broken ancient crater-ring resembling Somma. About the middle of the present century it also woke up after a long slumber and returned to work, this being associated with violent earthquakes. Mayon, farther north, is a cone remarkably regular in shape, approximately 8500 feet high, but apparently is without a terminal crater, the actual summit consisting of broken rock, from the cracks in which issue jets of sulphurous steam. Eruptions are frequent from a lateral crater, which discharges only ashes, but these in abundance. For instance, in 1814, the town of Daraga was buried and the dust was carried even to Manila, or more than 220 miles away. Floods of volcanic mud are not infrequent, which, as might be expected, are very destructive. During an eruption in 1872, the cone itself is said to have been split from top to bottom by a fissure which in places was between 100 and 150 feet in width. In the valley of Tibi, Southern Luzon, are hot springs, which deposit abundantly silicious sinter, as in the

building of the lost terraces of Rotamahana. Craters, active and extinct, with hot springs, also occur in the central part of the island, the most remarkable of the former being Taal, which rises in the middle of Lake Bombon. It has a large summit crater, with two of smaller size, one or other of which is occasionally in eruption. The lake itself, though its dimensions, about sixteen miles by eleven, are very large, probably occupies an ancient crater. It is said to have been once connected with the sea, from which at the present day it is separated by an isthmus two or three miles wide, composed entirely of ashes. Its waters are stated to be still slightly brackish, and its fish to be modifications of marine species. Volcanoes also occur to the north of Luzon, though less frequently, and these seem to have no special interest.

From the Philippine Islands we pass on by Formosa, which is mainly composed of continental rocks, though a line of weakness is indicated by a few extinct craters, to the Loo-choo Islands, which consist mostly of ancient crystalline rocks, with some of sedimentary origin, and are said not to contain any volcanoes. Sulphur Island, however, with a steaming crater, proves that an outburst in their neighbourhood is always possible, while in the smaller island groups to the north there are several volcanic cones, some of them active, the highest being about 5000 feet. These island groups mark the position of a second link in the set of great crescentiform submarine plateaux, the horns of which point to the Asiatic

coast, and they bring us to the commencement of a third in Kyushu, the southernmost of the larger islands of Japan, opposite to the great promontory of Korea.

Before describing the last-named islands we must glance at another line of weakness which can be traced, though with some uncertainty, from New Guinea to Japan. From the irregular peninsula which forms the north-western termination of the former, a submarine plateau runs first northward and then eastward, separating the large and profound basin, to which the Philippines form a western rim, from the smaller and shallower one designated Nares Deep. The former one communicates by a kind of trough or channel with the Challenger Deep, at the western end of which, and very near the channel, soundings have been obtained of 4575 fathoms. To the north of the last-named basin comes the still larger and yet more profound Tuscarora Deep,[1] bounded on the south-west by a plateau which extends southward from part of Nippon, starting rather on the western side of Tokio. This plateau, irregular in form and rather broken in outline, seems traceable down to the above-named channel, and thus to make a link with that which sweeps eastward to include Nares Deep and to support the Caroline Islands. On the former plateau islands are not very numerous, and many of them are only coral reefs; but here and there, as in the Mari-

[1] The deepest part lies parallel with the Japanese and Kurile Islands, and its lowest point found was 4655 fathoms.

anne Islands, volcanic rocks rise above water, and a few craters are still active, though not energetic.

Japan is essentially a region of terrestrial disturbances ; it is frequently shaken with earthquakes, the more ancient rocks of its mountain ranges often show every sign of intense pressure, and volcanoes are numerous, especially in the northern and southern parts, though somewhat scattered. The highest mountains are sometimes extinct craters, sometimes more ancient igneous rock. The chief sphere of volcanic activity is the backbone of the islands, where there are several silent cones rising to the height of from eight to ten thousand feet, with Asama-yama, an active crater, 8260 feet, and Bandai-san, near Lake Inawashiro, the scene of the terrible explosion already mentioned.[1] The beautifully regular cone of Fuji-san, or Fusiyama, the highest in Japan, for it attains to 12,365 feet, is in an isolated position, comparatively near to the sea, about seventy miles to the south-west of Tokio. It seems to be dormant, for no eruption has occurred since the year 1707. Its materials are andesitic, and this seems to be the most frequent volcanic rock in Japan. But considerably farther to the south-west the island of Oshima, on the coast of the southern promontory named Kii, was the scene of a great outbreak in 1878. Eruptions also are on record from several craters in the main island, now temporarily dormant, and a few insular volcanoes occur on its western coast.

[1] July 15, 1888 (see p. 16).

The Kurile Islands continue the curve of the Japanese from the north-east of Yesso up to the promontory of Kamtchatka. According to Professor Milne, their volcanoes are fifty-two in number, of which nine at least are still active, and he considers the remainder to be approximately of the same date as the more modern cones in Japan and Kamtchatka. Alexis Perrey thinks that as many as thirteen have ejected lava or ashes since the archipelago became known to Europeans, about 250 years ago. All of them, at any rate, have a remarkably fresh aspect, and earthquakes are frequent. Some of the cones are really mountains—the most elevated, Araid, is probably somewhere about 12,000 feet high.[1]

On the large peninsula of Kamtchatka a mountain chain, on approaching the broader part, opens out to form two ranges, running generally near to the respective coasts, and reuniting towards the north. The eastern range is the lower of the two, but includes the larger number of volcanoes. About a dozen of these have been active during modern times, and the highest of them, Klioutchevsk, is only a few yards lower than Mont Blanc. Besides this are Koriakovsk (11,221 feet), Chevlioutch (10,548 feet), and others of less elevation. Of extinct craters there are sixteen in this range, and only five in all in the western one. Some of them also are lofty, the highest, Ouchkin, being 10,926 feet. In the volcanoes

[1] The estimates vary by as much as 3500 feet. See Saint-Martin and Rousselet, *ut supra, s. v.* Kouriles.

which are still active, eruptions are frequent, and not seldom very violent, as were those of Klioutchevsk in 1727, 1737, and 1854.[1] Earthquakes also are frequent, but, fortunately, the peninsula is not thickly inhabited. Its northern part is the least disturbed, though here also are some hot springs.

It is thus evident that lines of weakness in the earth's crust form a connected series of curves, with their convexities towards the Pacific, along the whole eastern coast of Asia, and are then continued across Behring Strait into America. From New Guinea, which we took as a centre, another fracture or group of fractures can be traced in a south-easterly direction. The best defined of these passes along New Zealand, but as the whole region between the eastern part of Australia and the deeper and more central part of the Pacific is more complicated in its structure than those which we have been following, this line of disturbance can be more conveniently considered with the great Central Ocean; so we will pass across Behring Strait to the American continent, where the volcanic geography is even more simple than that which has been already described.

A zone of mountains extends along the whole western flank of the American continent, from the northern to the southern extremity. This, from Alaska to Terra del Fuego, is associated with volcanoes, though the vents are only locally active, and in the majority of cases the craters are either ruinous

[1] Saint-Martin and Rousselet, *ut supra*, *s.v.* Kamtchatka.

or have disappeared. In the extreme north, a volcanic belt extends from the head of Cook's Inlet on the east through Alaska and over the Aleutian Isles towards the district already described. The higher mountains, however, so far as is at present known, are not volcanic—Mount St. Elias, about 18,000 feet, certainly is not. The same is probably true of its yet more lofty neighbour, Mount Logan, and the other summits near the frontier of British and United States territory; the Alaska coast also, which forms a fringe to this region, seems to be free from volcanoes, and the same is true of South-eastern Alaska and its islands, with the exception of Mount Edgecumbe, an insular volcano which is reported to be a basaltic crater about 2855 feet high, and to have been active in 1796. Eruptions are said to have occurred from Mount Calder and other summits on Prince of Wales Island at a slightly earlier date; but these, as Professor I. C. Russell informs us,[1] are as yet very imperfectly known. The most conspicuous and best-marked belt begins at Cook's Inlet on the east, and extends through the Alaskan promontory to the Aleutian Islands. It is about a thousand miles long, but generally less than forty miles broad. In fact, every volcano in it which is known to have been active in historic times can be included between two lines on the map of Alaska, twenty-five miles apart. Craters in good preservation are numerous, and active vents

[1] *Volcanoes of North America*, which is taken as the authority for this continent throughout.

not few, one of which has been already noticed.[1] They occur either close to the sea on the southern border of the mainland or on islands. To this statement as to the geographical distribution one exception is known; some small cones, also of basalt, occur near St. Michael on the coast of Behring Sea, about seventy miles north of the mouth of the Yukon River; but there may be others, for at present not much of Alaska has been carefully investigated by qualified observers. On Copper River, some 200 miles to the north-east of Cook's Inlet, and thus apparently insulated from the Aleutian belt, rises Mount Wrangel, a lofty volcano, which was in eruption in 1819 and is still steaming,[2] and others of the neighbouring mountains may have the same origin. On the western shore also of this inlet are two fine volcanic peaks, Redoute and Iliamna, reported to be about 11,000 and 12,000 feet high. The latter is generally steaming, and a few years ago discharged such a quantity of dust and lapilli that the forests were killed over hundreds of square miles on the adjacent lowlands.[3]

From this district to Central America no active vents exist, though they were once plentiful. In the Canadian territory to the south and east of United States Alaska very little is at present known of its volcanic history. There are lava sheets about the

[1] Page 48 *et seq.*

[2] Including this, Professor Russell reckons 57 active or recently extinct craters, 48 of them being in the Aleutian Isles, and of these 25 are still active.

[3] The ejected materials from these volcanoes seem more commonly basaltic, but obsidian occurs at Unimak Island and andesite at Bogosloff.

Fraser River of enormous extent, but Dr. G. M. Dawson did not discover here any distinct traces of craters, so that very probably this portion of the American continent may be compared with the northern side of the Atlantic basin, where discharges anciently occurred from Antrim at least as far as Iceland, but now continue only in the latter region.

The Columbia lavas, vast sheets of basalt, have been already mentioned; but here, as in the Fraser River district, cinder cones and craters are wanting, and the eruptions probably date from about the middle of the Tertiary era. They lie to the east of the Cascade Mountains,[1] in which volcanoes have certainly existed, but whether any retain their craters does not seem to be as yet ascertained. There is a tradition that Mount Baker, a fine peak to the west of the main chain and in the northern part of the district (near Puget Sound), broke out in 1843, but on this point Professor Russell is doubtful. Mount Rainier, however, a superb peak, not only from its elevation, 14,525 feet, but also because it rises practically from sea-level, still emits some steam. The highest part is a cone built up within the shattered ring of a much older crater, and the materials appear to be basaltic. Mount St. Helen's (9750 feet), also detached from the main mass, is said to have been in eruption in 1841–42, and fumaroles still exist on the slopes. Mount Adams (9570 feet), farther south and rather east of the main range, apparently retains a crater.

[1] These are a northward continuation of the chain of the Sierra Nevada.

On the crest of the Cascade Mountains, in North-western Oregon, Mount Hood rises to a height of 11,225 feet, and is noted for the beauty of its outline. Portions only of the wall of its summit crater now remain, but there are still fumaroles at considerable elevations on the north-east and the south sides. Mount Jefferson (10,200 feet) and the Three Sisters, a little farther south, in the Cascade range, are the sites of ancient volcanoes; but their craters apparently have perished, and to the south of these come others of less elevation, which for the most part retain craters either at their summits or on their flanks, the most important of them being Crater Lake or Mount Mazama, which has been already described.[1]

Yet farther south comes the noted mass of Mount Shasta, rising to a height of 14,350 feet. The summit crater is ruinous, and the slopes are scarred with ravines; but lava streams have flowed down its flank since the Glacial epoch, and a distinct subsidiary crater remains on a lower summit called Shastina. Farther south comes a volcanic district named Lassen's Peak from its principal summit, which rises to an elevation of 10,437 feet. This is crossed from north-west to south-east by a belt of volcanic cones about fifty miles long by twenty-five miles wide; one of them, Cinder Cone by name, being remarkably well preserved. The crater, as illustrated by Professor Russell,[2] is a double one, and there were two

[1] Page 121.

[2] From the *Geological Atlas of the United States* (Lassen Peak), by J. S. Diller.

distinct periods of eruption. In the earlier a quantity of ash was ejected and the cinder cone itself was formed. Then there was a pause long enough to allow ten feet of diatomaceous earth to accumulate on the bed of an adjacent lake, and after that came the quiet effusion of a large sheet of lava.

East of the Sierra Nevada, on the area once occupied by a great sheet of water now spoken of as Lake Lahontan, are two ancient craters filled with alkaline water. The greater, which has an area of about 268 acres, only rises some eighty feet above the level of the surrounding country, so that it resembles, though on a larger scale, such a crater as the Pulvermaar in the Eifel. Geological evidence shows that these were active during the existence of Lake Lahontan, and that before they ceased it had already begun to dry up. In the Mono valley, also east of the Sierra Nevada, but farther south, and near to the lake of the same name, are a number of craters, some not much elevated above the surrounding country, but others rising to over 2000 feet, with lava streams and fumaroles. The materials apparently consist of basalts and varieties of andesite; but the Mono craters, as the line of higher cones is called, have ejected rhyolite and even obsidian. Professor Russell remarks that these cones (some of which have lost their craters), though forming an isolated group, are really a portion of a much more extended series of recent eruptions, which follow the general course of the great belt of branching faults by which the eastern face of

the Sierra Nevada has been determined. The fact that, as a rule, the central cones are the less perfectly preserved and are the older, shows that "the volcanic energy early in the history of the range evidently found an avenue of escape where [they] now stand, and when the conduits of these craters became clogged newer craters were formed, both to the north and south, along the same line or belt of fracture."

To the west of the Wahsatch Mountains, in the inland basin of Utah, and on the area once occupied by the great sheet of water designated Lake Bonneville, are the Ice Spring Craters, a group of low craters, three of which are very well defined, though they are breached by streams of basaltic lava, which cover an area of over twelve square miles. Other craters occur in the district, some being older and some newer than Lake Bonneville, while others were active during its existence.

In Northern Arizona the San Francisco Mountains are volcanic. The higher summits, which rise to a mean elevation of 12,562 feet above the sea and about 5700 above the general level of the surrounding table-land, consist largely of trachytic lavas and have lost their craters; but around them are numerous small craters of basaltic scoria, which often are well preserved and are associated with flows of the same rock. Some of these have been breached by the lava, which has welled up in their interior and has escaped exactly as was described by Scrope in his book on *The Volcanoes of Central France*. In one, however, a lake is sheltered.

Just east of the crest of the Rocky Mountains, and in the north-west corner of the State of Wyoming, is the far-famed volcanic district of the Yellowstone Park and its neighbourhood. Craters apparently are not common in this region, but the great flows of obsidian have attracted much attention from geologists. This volcanic glass is associated with pumice, the rocks generally being trachytes, usually rich in silica. The vents are now extinct, unless a mud volcano be regarded as an exception; but the hot springs and geysers to which the Park owes its world-wide fame show that a high temperature still prevails, probably at no great depth below the surface. The vast flows of basalt in the valleys draining to the Snake River in Idaho, to which reference has already been made,[1] are on the western slope of the Rocky Mountains, but at no very great distance from the Yellowstone Park. Also east of the Rocky Mountains, in the State of Colorado, are several cones and flows of basalt, while to the south of Pucho the bold summits of the Spanish Peaks, which rise respectively to heights of 12,720 and 13,620 feet above the sea, are ancient volcanoes; but in all these the craters seem to have been destroyed. The materials are described as trachytes, some varieties approaching rhyolite. Farther south, however, in the State of New Mexico are several extinct volcanoes, some of which retain their craters in good preservation. The materials, so far as described, are basalt. Mount Taylor (11,390 feet) also is the centre of a

[1] Page 133.

volcanic district. Its crater has perished, but these remain on some of the smaller neighbouring cones. The rock apparently is basalt.

The long peninsula of Lower California may be regarded as a prolongation of the chain of the Sierra Nevada. It also contains many extinct volcanoes, which, however, are at present but imperfectly known. Towards the north, according to Professor Russell, Mount Santa Catalina rises to a height of some 10,000 feet, and about the middle is a group of volcanic peaks known as the Tres Virgines, the highest of which is said to be 7250 feet. In this group an eruption occurred in 1857, and since then steam has been ejected, sometimes in great quantity.

Those described above, as Professor Russell remarks, are only some of the most striking instances among the hundreds of lava-flows and craters within the United States; but it will be noticed that the great majority are associated with the second one of the three mountain chains which form the western flank of the North American continent, the huge eastern mass of the Rocky Mountains being almost entirely, and the smaller western one of the Coast Range being wholly, free from volcanoes of recent date. The Sierra Madre in Mexico, which may be regarded as a prolongation of the Rocky Mountains, appear to exhibit no signs of recent volcanic action.

Thus a very considerable space separates the volcanoes of the part of Mexico which lies south of the tropic of Cancer, a region of great activity even in

the present day, from those of which we have been speaking. The former also appear not to lie, as usual, along a belt parallel with the western coast, but to be rather irregularly distributed over one, about 150 miles in breadth, which extends from sea to sea in a general direction from W.N.W. to E.N.E. for not much less than 600 miles. All the volcanoes in Mexico which are still active (ten in number according to Reclus) lie south of latitude 22°. The most northerly of them is Ceboruco (about 7140 feet) on the Pacific coast, the centre of a group of craters, which was in eruption in 1870 and has continued steaming ever since. Farther south near the same coast is Colima, which has frequently been active. In 1885, the dust from it was carried to the north-east for a distance of 280 miles.

Proceeding eastwards, and slightly to the south, we come to Jorullo, the eruption of which, ever since the days of Humboldt, has figured so largely in geological text-books. This for many years was quoted as an example which very strongly supported the elevation theory of volcanic cones. It was asserted that here a tract of land, from three to four miles in extent, had almost suddenly swelled up like a bladder, while cones were built by discharges from its surface and at its sides. This happened on the night of September 29, 1759; but, as has been frequently shown, the evidence for this remarkable phenomenon is quite untrustworthy. As we proceed eastwards the volcanoes become more lofty. Xinantecatl,

some forty miles south-west of the city of Mexico, crowned by two crater-lakes, rises to about 15,000 feet; but east of that city are two giants, Ixtaccihuatl to the north, and Popocatepetl to the south. The former, which, however, has lost its crater, is hardly less, perhaps more, than 16,500 feet; but Popocatepetl is about 1200 feet more than this, and terminates in a crater from which a little steam issues. The lower part of the mountain consists of basalt, but the great cone is mostly composed of andesite,[1] and its summit is described as trachyte. Yet farther to the east come Cofre de Perote and Orizaba, which also lie on a north and south line; the former, which is composed of hornblende andesite, has lost its crater and is only 13,552 feet high; but its companion is the highest volcanic summit on the northern continent. The exact measurement is uncertain, but it cannot be much, if at all, less than 18,000 feet. On the summit are three craters in good preservation, and the flanks of the mountain are studded with small cones. Its last eruption is said to have occurred in the eighteenth century. Finally, on the eastern coast is Tuxtla, reported to be a little less than 5000 feet high, which is active from time to time. A terrible eruption occurred, after a pause of nearly 120 years, in March, 1793. A series of violent explosions considerably reduced the height of the mountain and scattered ashes over a large area. The fine dust was borne by the wind about 150 miles to

[1] The variety containing hypersthene.

the north-west, and the same distance to the south-west. This fact suggests that, as happened to a less extent in an eruption of Cotopaxi,[1] part of the dust was shot up into a region where an upper stratum of air was moving in a different direction from the lower one. Still in Mexico, but considerably to the south of the belt described above, and on the shore of the Pacific, is Chacahua, an extinct crater, while to the east of it is Pochutla, a volcano which after a very long period of repose exploded in 1870.[2]

From Guatemala to Costa Rica is a zone marked by great volcanic activity, which follows the line of the Pacific coast. Some of the cones on this rise to elevations considerably above 10,000 feet, but the majority do not exceed 8000. In Guatemala, according to a list given by Professor Russell,[3] there are two active volcanoes, four quiescent, and fifteen extinct. Among the last-named is Tajamulco, which lays claim, though probably without warrant, to an altitude of 18,317 feet. In San Salvador five are active, three quiescent, and the same number extinct. Honduras, which lies chiefly to the east of the mountain axis, is without an active volcano, but has two quiescent and three extinct. Nicaragua contains four active, eight quiescent, five extinct, while in Costa Rica one only can be called active, and its last eruption was as long ago as 1726, while two are qui-

[1] See page 42.
[2] Reclus, *Nouv. Géogr. Univ.* (Indes Occidentales), p. 52.
[3] *Ut supra*, p. 139.

escent and six extinct. Lastly, at the northern part of the Isthmus of Panama are three mountains of volcanic origin, two of them over 11,000 feet high, but it is doubtful whether any one retains a remnant of a crater.

Three of the volcanoes in the above-named list are especially interesting, because, like Monte Nuovo,[1] the history of their actual birth is recorded. Two of these are in San Salvador, the third in Nicaragua. Of the former, Izalco, now rising about 3000 feet above the surrounding country and 5000 feet above sea-level, began to be formed in the year 1770. It covers what previously was a fine cattle-farm. "The occupants on this estate were alarmed by subterranean noises and shocks of earthquakes about the end of 1769, which continued to increase in loudness and strength until the 23rd of the February following, when the earth opened about half a mile from the dwellings on the estate, sending out lava, accompanied by fire and smoke." The eruption thus begun went on continuously, lava sometimes being ejected, but at others only ashes and volcanic bombs, and thus the cone has been built up to its present height. No lava has been discharged for many years, but ashes and dust, mingled with steam, are constantly ejected. There are three craters, the central one being the largest and most active. Acid vapours also are emitted from fumaroles. Lake Ilopango, which possibly occupies an ancient crater, also in San Salvador, wit-

[1] See page 10.

nessed the beginning of a volcano as lately as the year 1880. A violent earthquake in 1879 was accompanied by a rising of steam from the lake, and was followed by a steady fall in the level of its waters, amounting to about thirty-five feet. Then, during the night of January 20, 1880, the surface of the lake was again agitated, and the next morning a pile of rocks was observed in the centre, from which rose a column of vapour. The eruption lasted for more than a month, sulphurous vapours were emitted copiously, the fish in the lake were killed, and a cone was ultimately formed about 160 feet above the water, but rising from a depth of some 600 feet.

A new volcano broke out on April 11, 1850, in Nicaragua, in a district called the Plain of Leon. This is studded with cones, of which one at least is active. The commencement of the eruption was not carefully observed, but the outbreak occurred near the base of an extinct crater called Las Pilas. It began with a copious discharge of lava. This ceased on the 14th of the month, and was succeeded by a different phase of action, namely, a series of paroxysms lasting about three minutes, with intervals of about the same length. By these, steam, ashes, and red-hot bombs were shot up to a height of several hundred feet, accompanied, it is said, by outbursts of flame. Thus in the course of a week a cone was built up to a height of from a hundred and fifty to two hundred feet, after which the action became much more intermittent.

Among the older summits of Central America it may suffice to mention three, all of which are lofty mountains. Volcan de Agua, 12,213 feet, at the time of the Spanish invasion was a crater-lake. In the year 1541, after an earthquake, the wall of the crater gave way on the north-eastern side and the water escaped, doing great damage as it rushed down the slope of the mountain. Fuego, to the east, with its group of three volcanic cones, the highest of which attains to 13,943 feet, was often active in the sixteenth and seventeenth centuries, and probably for some long time previously; but since then eruptions have been less frequent, though one occurred as late as 1860, and steam still issues from the crater. But the most noted of all is Conseguina, for it was the scene of a frightful eruption in the year 1835. So far as is known, this, like the famous awakening of Vesuvius in the year 79, put an end to a long period of complete repose. It began on the morning of January 20th, when several loud detonations were heard, followed by the ejection of a cloud of inky smoke, through which "darted tongues of flame resembling lightning." The cloud spread gradually outwards, obscuring the sun, while fine dust fell from it like rain. This went on for two days, the sand falling more and more thickly and the explosions becoming louder and louder. On the third day they reached a maximum and the darkness became intense. The quantity of material that fell was so great that for leagues around people actually deserted their

houses, fearing lest their roofs might be crushed in. At Leon, more than a hundred miles away, the dust lay several inches deep, and it was carried to Jamaica, Vera Cruz, and Santa Fé de Bogota, over an area of 1500 miles in diameter. The sea also was covered with floating masses of pumice for a distance of some fifty leagues.[1] During the eruption the height of the cone was considerably reduced, but to what extent is not certainly known ; probably by at least one half, for it is now a crater four miles in diameter and only 3600 feet above the sea. Many of the phenomena during this outbreak closely agree with those associated with the first eruption of Vesuvius and that of Krakatoa already described.[2]

The Isthmus of Panama, though its hills in places are comparatively low and without volcanic cones, links together the great mountain chains of North and South America. But that of the Andes, which extends along the whole western flank of the latter, is rather less complicated in structure than the system of the former country. It is a single chain, consisting partly of sedimentary, partly of igneous rocks, old and new, both crystalline and volcanic. The sedimentaries and the older igneous form the lower part of the great mountain wall, and the volcanoes, generally speaking, rise more nearly from its crest than from its flanks. They are not, however, continuous

[1] About a month later there were fearful earthquakes along the Andes, in one of which the town of Concepcion in Chili, which had 25,000 inhabitants, was so completely destroyed that only one house was left standing.

[2] Pages 3 and 20.

along the whole chain, but form three principal groups —those of Colombia and Ecuador in the north, those of Bolivia in the centre, and those of Chili in the south. About sixty craters are still active; those which are extinct and more or less ruined may be counted by hundreds.[1] The first group, in the more northern part, consists of three principal ranges, of which the eastern one branches out at last into the great mountains which runs roughly parallel with the border of the Caribbean Sea. The western range is less elevated than the others, at any rate in its more northern part; the central, on which the volcanoes are chiefly situated, supports many lofty peaks. Of these Mesa de Herveo, 18,340 feet, retains its ancient crater; Ruiz, 17,189 feet; Tolima, 18,392 feet; and Huila, 18,701,[2] all show some signs of life. An eruption occurred at Puracé, 15,425 feet, in 1849, when the torrents of mud caused by the rapid melting of the snow caused much devastation. Extinct volcanoes are also frequent. In the eastern chain no vents are mentioned as active.

Passing into Ecuador, the volcanic summits, according to Mr. Whymper,[3] are grouped along two roughly parallel lines. On the western, Cotocachi, Pichincha, Corazon, Illiniza, Carihuairazo, and Chimborazo are the most important[4]; on the eastern, Cayambe, Anti-

[1] Reclus, *Nouv. Géogr. Univ.* (South. America), p. 27.

[2] This, if the correct height be given, is the most elevated in the country; but some statements make it lower by about 650 feet.

[3] *Travels in the Great Andes of the Equator*, 2 vols., 1892.

[4] The following are the heights given by Mr. Whymper: Cotocachi, 16,301

sana, Sincholagua, Cotopaxi, Altar, and Sangai. Of these the majority have lost their craters, including Chimborazo.[1] Altar retains one, so does Pichincha, which apparently is hardly extinct, while Sangai and Cotopaxi, which has been already described,[2] are still active. It may suffice to say that the specimens brought back by Mr. Whymper were almost without exception varieties of andesite, several of them containing hypersthene.[3] Antisana, however, also furnished a pitchstone. The volcanic cones, according to Reiss and Wolf, continue for some distance to the south of those which have been mentioned.

In the Peruvian and Bolivian Andes we find the second linear group of craters. The same arrangement in parallel lines seems to continue, and the highest summit, Huascan, is said to overtop Chimborazo by rather more than 1300 feet. Volcanic cones are most frequent in the southern part of the western range, where they set in again some 1200 miles from those of Ecuador. Few, however, are mentioned as active in historic times; among them Ubinas, Omate, Candarave (18,964 feet), are enumerated by Reclus.[4] But among the extinct volcanoes

feet; Pichincha, 15,918 feet; Corazon, 15,871 feet; Illiniza, 17,405 feet; Carihuairazo, 16,515 feet; Chimborazo, 20,498 feet; Cayambe, 19,186 feet; Antisana, 19,335 feet; Sincholagua, 16,365 feet; Cotopaxi, 19,613 feet; Altar, 17,730 feet; Sangai, 17,474 feet. *Ut supra*, chap. xix.

[1] The top is a snow dome. This may conceal a crater, but from the general aspect of the mountain I think it not very probable.

[2] Page 39 *et seq.*

[3] That is to say, the peculiar variety of this mineral named amblystegite by Von Rath.

[4] *Ut supra*, p. 502.

some also rise to great heights, such as Sara-Sara, Achatayhua, Coro Puna, Ampato, Misti, and Chachani, all of which exceed 13,000 feet, the last reaching 19,767 feet and Misti 18,504 feet.

This volcanic group continues into Bolivia, and there are some active craters, especially near Lake Titicaca. Presumably the higher peaks of this country, five of which are enumerated as over 21,000 feet, and the highest, Illimani, reaching 22,350 feet,[1] are volcanic, and the last is said to smoke constantly. Altogether, sixteen craters are asserted to be active in this second group of Andes volcanoes, of which at present our knowledge is rather imperfect.

Passing on to the third group, the volcanoes of Chili, we find these numerous, though for the most part they have long ceased to be active. In the northern part, however, two at least, Llullailaco (17,061 feet) and Doña Inez, are still at work. In the middle are the highest summits—Aconcagua, 22,867 feet; Cerro del Mercedario, 22,302 feet; Tupungato, 20,269 feet; San José, 20,000 feet; and Maïpo, 17,657 feet. Of these, Aconcagua has entirely lost its crater, and Tupungato retains no distinctive trace of it, but one or two vents are still active; one, about 13,000 feet high, lying some twenty miles to the south-west of Tupungato. In this part also, according to Mr. FitzGerald,[2] the Andes consist of two ranges, of which the western is the watershed; the

[1] Saint-Martin and Rousselet, *ut supra*, *s. v.* Bolivia.

[2] *Proc. Roy. Geogr. Soc.*, vol. xi., p. 678.

other supports the highest peaks. There is also a third and eastern range, but this is separated from the main chain by a valley only about 4000 feet above sea-level. The rocks brought back by Messrs. FitzGerald and Vines are mostly andesites, the actual summits of Aconcagua and Tupungato being the hornblende-bearing variety of that rock, though a rhyolite or dacite was obtained on the flank of the latter mountain.[1] The volcanic line does not completely come to an end with Chili, for Corcovado (7510 feet) in the Patagonian Andes is a volcano; but though there may be some extinct cones yet farther south, the active vents are not continued to Cape Horn.

By returning to New Guinea we can trace another line of weakness in the earth's crust, from the Admiralty Islands, which are situated nearer to its north-eastern extremity, through the Bismarck Archipelago, the Solomon Islands, and the New Hebrides, in the direction of New Zealand. These groups are largely volcanic and include some active craters, as in New Britain, which, however, do not attain any great elevation. Ténakaro, on one of the northern islands of the Santa Cruz group, between the Solomon Islands and the New Hebrides, is always in eruption. New Caledonia, however, which lies rather to the west of this zone of disturbance, contains no volcanoes, and is mainly composed of continental rocks. Much the

[1] They have been examined by myself, and will be described in Mr. FitzGerald's account of his travels.

larger part of the New Zealand group also consist of these, but here eruptions occur. The principal volcanic region is on the west side of the main chain of the North Island. Here are two extinct volcanoes—Mount Egmont, 8270 feet; Ruapehu, 9195 feet; with Tongariro, 7000 feet, which is still active. So also is a vent on White Island in the Bay of Plenty on the eastern coast.

The district around Lake Taupo, which is also in the North Island, about the middle of the broadest part, is studded with cinder cones and lava-flows, and between this sheet of water and the Bay of Plenty are the volcano of Tarawera and the hot springs of Rotomahana. The terraces of silicious sinter formed by the latter were one of the wonders of New Zealand till 1886. On the 10th of June in that year, the volcano, a flat-topped cone rising about a thousand feet above the lake of the same name, and supposed to be extinct, suddenly broke out, throwing up quantities of pumice mingled with steam to a height of nearly four miles. The whole country round, including these beautiful terraces, was buried deep beneath the fallen *débris*. In the South Island, Banks' Peninsula has had a volcanic origin, and similar rock occurs in one or two isolated localities; but the only signs of activity are off the eastern coast, where submarine eruptions have been observed.

The line of active volcanoes in New Zealand[1] seems

[1] For most of the statements in this paragraph see Berghaus, *Physikalischer Atlas*, Pl. 3.

to continue northwards through the Kermadec Islands, also volcanic, towards the Tonga Islands. In fact, the North Island is probably situated at the junction of two zones of weakness, viz., the one named above as passing down by the New Hebrides, and that just mentioned. After uniting they form a single band along the eastern side of the South Island, and this is prolonged to the Macquarie Islands, which are said to be volcanic. Here, if this line extend to the Antarctic land region, it must bend a little towards the east and pass along the edge of Victoria Land, where Mount Erebus, 12,367 feet, is active, and its lower neighbour, Mount Terror, probably with other summits, is now dormant.

No active volcano is known to occur on the mainland of Australia, but there are extinct craters with lava streams (basalts) in the eastern part of the colony of Victoria, and Blue Lake, in South Australia, occupies a crater. Not one, so far as I can discover, remains in Tasmania, although igneous rocks of older date are found there.

From the Kermadecs, as already said, we are led to the Tonga Islands, and then pass out into the more open part of the Pacific. Here it becomes very difficult to associate the vents, whether extinct or active. There are many groups, and such islands as are not atolls are volcanic; the majority, however, are remarkable in rising rather abruptly from deep water. Captain Field, in his recent survey of islands in the Ellice group, found that the ocean floor commonly lay about

2000 fathoms below the surface. Funafuti, for instance, which is one of these, rises at first slowly, then with a gradually steepening slope from that depth to about 800 feet from the surface, when its sides become almost precipitous. This portion is supposed with good reason to be the atoll,[1] namely, to be composed of coral and other calcareous organisms; but the larger and lower part, the nature of which is of course unknown, suggests the probability that the foundation is volcanic. Whether this be a denuded cone or a mass of ejected material which never reached the surface, or whether Darwin is right in regarding an atoll as a monument set up by Nature to the memory of a drowned island, is one of those questions on which we may hope light will be thrown by the recent investigations at Funafuti.

The Tonga Islands are mainly volcanic, some craters being still active, especially in Tofua and its neighbours; submarine eruptions also are not rare, and, in 1881, an island appeared above the sea. Kao Island is an extinct cone, about 5000 feet at its highest point. Laté, in 1854, was the scene of a violent eruption, and so was Amargura in 1846. The ejected materials, so far as I can ascertain, were basaltic. In the Fiji Islands to the west are some extinct but no active craters. The disposition of the islands and craters in this part of the ocean suggests the existence of a group of parallel fissures, forming transverse connections between the two forks, which, as already men-

[1] *Proc. Roy. Soc.*, vol. xlii., p. 200.

tioned, branch out from the northern part of New Zealand. The position of one may be indicated by the Fiji Islands; Niua-fu, with some small islands to the west, may denote another; Samoa stands on a third. Niua-fu is a large oval island with a crater-lake; an eruption took place here in 1886, when a quantity of pulverised basalt-glass was ejected.[1]

In Samoa lava-flows and cones are abundant, but none of the latter are active, though in regard to one a tradition èxists among the natives. They are more ruinous in the south-eastern part of the group than in the south-western. The small archipelagoes of the Society, the Low, and the Marquesas Islands to the north-east, and Easter Island to the south-east, are all volcanic, but require no special notice except that, according to a map given by Reclus,[2] the former probably indicate lines of weakness, all running from north-west to south-east. In Samoa, one in the same direction crosses another fissure at right angles, a parallel to the latter being more nearly found in Easter Island.

The Sandwich or Hawaiian Islands are a group of huge volcanic cones, occupying a zone running from W.N.W. to E.S.E., and rising from the ocean floor, which is at a depth of over 2000 fathoms. These islands, except for some coral reefs attached to their margin, are wholly volcanic; the rock is basalt, and lava enters very largely into the formation of the masses which are above water. As some account has

[1] See p. 70. [2] *Nouv. Géogr. Univ.* (Océan et Terres Océaniques), p. 895.

already been given of the Hawaiian group,[1] it may suffice to say that all but three of the vents are now extinct, the total number being fifteen. The active craters are on Hawaii, the easternmost and largest island. These are Kilauea, 4040 feet; Hualalai, 8273 feet; and Loa, 13,675 feet. Two other volcanic cones go to make up this island, one of them, Kea by name, even overtopping Loa, for it rises to 13,805 feet. The two cones in Oahu have lost their craters; of the pair in Maui one crater has perished, but the other is very fresh-looking. All the eruptions which have taken place for the last three quarters of a century have been non-explosive; but, according to tradition, Kilauea was the scene of one more violent in 1789. In the Pacific Ocean but a single group of volcanic islands still remains to be noticed. These are the Galapagos, which lie under the equator, nearly 600 miles west of the coast of South America. The group includes five principal islands and several of small size, all volcanic. Vents are active on Albemarle Island, the largest, and on Narborough Island, the third in size, while streams of lava on others have a very fresh appearance. The former rise to heights of from one to four thousand seven hundred feet, and the craters vary in size from mere blow-holes to "huge cauldrons, several miles in circumference"; their number is very large, probably over two thousand. The lavas are basaltic. According to Darwin[2] the

[1] See pp. 25-35, also 77 and 84.
[2] "On Volcanic Islands," *Geology of Beagle*, part ii., chap. v.

volcanic orifices are not indiscriminately scattered, for three of the great craters on Albemarle Island lie on a line running from about N.N.W. to S.S.E., and the others may be arranged on three lines all parallel with the above.

The whole eastern coast of both Americas is entirely free from volcanoes of anything like recent date,—indeed, we might say the whole western border of the Atlantic, were it not for the long island chain of the Lesser Antilles, which separates that ocean from the Caribbean Sea.[1] Many of these are limestone, chiefly coralline; some contain crystalline rocks, but others are volcanic. Seven craters still give signs of life by emitting steam, or by the presence of fumaroles on the slopes, but many others are completely extinct. It is noteworthy that this curving line of vents occurs on a submarine plateau between the deep basin of the central Atlantic and that of the Caribbean Sea.

But few groups of islands interrupt the surface of the Atlantic Ocean, and these are almost exclusively volcanic. The Azores rise from the submarine plateau which, starting from that connecting Greenland and the British Isles, may be traced down the middle of the North Atlantic. Madeira seems to be linked with the Spanish coast; the Canary and the Cape Verd Islands are more closely connected with the African mainland. The Azores are volcanic masses of

[1] The islands of Fernando Noronha, off the Brazil coast, and nearly under the equator, are largely of volcanic rock (basalt and phonolite), but apparently no craters remain.

basaltic lava and scoria, rising like the Sandwich Islands from comparatively deep water. An eruption occurred in Pico in 1572, in St. George in 1580, in Terceira in 1614, and in Fayal in 1672; but San Miguel has been more frequently disturbed by both eruptions and earthquakes, and the former have been sometimes submarine, as in June, 1811, when the islet named Sabrina was thrown up about half a league from the western extremity of the main island. In Madeira the older lavas are trachytic, the newer and far the more abundant are basalts. Some cinder cones exist, but only two craters have been preserved, and there are not even fumaroles or hot springs.

The Canary Islands are wholly volcanic, consisting partly of trachytes, but more largely of basaltic materials. Teneriffe, the largest island, culminates in the well-known "Peak," or Pico de Teyde, which rises to a height of about 12,200 feet above sea-level. This is a more modern cone thrown up within the ring of an ancient and broader crater. The rocks of the higher part of the mountain are trachytes, and locally even obsidian, but the major part is basalt—lava and scoria. The summit crater exhales a small quantity of steam and this issues from several subsidiary craters. In the concluding decade of the last century lava was discharged from more than one fissure on the slopes of the mountain. No eruption has occurred in Fuerteventura since the Spaniards took possession. The crater on Graciosa is extinct. Hierro and Grand Canary have hot mineral springs. Lanzarote has

suffered considerably. In 1730, a violent earthquake, followed by an eruption, did serious damage to half the island, and in 1825, during another eruption accompanied by earthquakes, two hills were thrown up, from which steam still rises. The huge crater, the Caldera, nine miles in diameter, in the island of Palma, has often been described, and from another one in the southern part there was a destructive eruption, also associated with an earthquake, in 1677. The Cape Verd Islands, though of volcanic origin, for they consist of basaltic materials, appear not to retain craters or to have been the scene of eruptions in recent times.

Ascension, which crowns a submarine plateau, corresponding with that named above, but in the Southern Atlantic, is another mass formed by volcanic eruptions. There are many cones, the highest summit rising to a height of 2870 feet, but all the craters are extinct ; both obsidian and basalt are found. St. Helena, connected with the eastern side of the same plateau, is also volcanic, consisting apparently of basalts with andesites and some phonolites ; but its vents have been so long extinct that the craters have perished. The Tristan d'Acunha group is one of the most isolated in the world, for it is about thirteen hundred miles south of St. Helena, and still more distant from either the Cape of Good Hope or Cape Horn. It consists of three islands, all volcanic, the rock being basalt, the largest culminating in a central cone which rises to a height of 7100 feet. A crater-

ake is said to exist on its summit.[1] Some of the small islands yet farther south in the Atlantic are volcanic, and there is an active vent on one of the Sandwich group. Bridgeman Island, to the north of Louis Philippe Land, appears to be a volcano, but the islands in this region consist often of sedimentary rocks.

On the African continent volcanic action seems for long past to have been but local and sporadic. On the western coast the only important centre is at the Cameroons Mountains, with the adjacent island of Fernando Po. The highest peak of the former, described by Sir H. H. Johnston,[2] terminates in three craters, apparently of basaltic scoria, and others occur on its flanks. On the eastern side of the continent the belt of extinct craters in South-western Arabia extends across the Strait of Bab-el-Mandeb into Somali Land. There are also some isolated volcanic masses along that zone of crust disturbances,[3] which can be traced for a long way down Eastern Africa, and perhaps begins even as far north as the Jordan valley in Asia.[4] On this zone is the only group of active vents known to exist on the continent. A small one was discovered by Count Teleki at the southern end of Lake Rudolf. It was seen by

[1] *Voyage of the Challenger*, "The Atlantic," vol. ii., chap. iii.

[2] *Alpine Journal*, xiv., 253.

[3] The volcanic zone, according to Dr. Gregory, lies to the west of a great axis of ancient rock, and may be followed, at any rate, as far as Abyssinia.—*Great Rift Valley*, part iii., chap. xii.

[4] In the highlands of Abyssinia there has been great volcanic action in past time, but whether any craters remain is doubtful.

[redacted]

Dr. Donald Smith, but, in 1896, Mr. Cavendish[1] found that this cone had been destroyed, and a flow of lava had occupied its site, but that another vent had opened a short distance away. There is also a crater, nearly two miles wide, called Mount Lubur, on the western side of Lake Rudolf. Hot springs are associated with a volcano about thirty miles to the south, and other cones occur in this region, some nearer Lake Baringo. Mount Kenia, however, which was explored by Dr. Gregory,[2] is a volcanic mountain on a grand scale, for it is about 19,000 feet high, but its crater has evidently perished. To the south-west is Longonot, about 9350 feet high, ascended by Dr. Gregory.[3] It has a well preserved crater, from which a little steam is still exhaled, the material being trachyte and obsidian. In this neighbourhood he examined a second and more denuded cone called Doenyo Nyuki, besides seeing one or two others at a distance.

A few isolated volcanic masses lie on the same highland zone, the most important being that of Kilimanjaro, about three degrees south of the equator. Two summits rise from an elevated volcanic plateau (some thirteen or fourteen thousand feet above sea-level), both extinct. The lower, Mawenzi, at the eastern end, is a jagged mass, 16,720 feet high, which, like Kenia, has lost every trace of a crater; but Kibo, about nine miles away at the other end,

[1] *Proc. Roy. Geog. Soc.*, vol. xi. (1898), p. 390.
[2] *Ut supra*, part ii., chap. x.
[3] *Ut supra*, part ii., chap. vi.

still retains it, though with a narrow breach in its western flank. The highest point of the ring is 19,720 feet above sea-level, and it is nearly a mile and a half in diameter, containing a small cone of later eruption towards its northern side.[1] The rocks are varieties of basalt, or occasionally of andesite, in some cases containing nepheline ; in others, though rarely, small leucites.[2] The volcanoes along this highland zone seem to occur as lofty, isolated masses rather than as connected ranges or thickly scattered vents, imitating Etna more nearly than either the Andes or the Phlegræan Fields. No vent of importance appears to occur to the south of Kilimanjaro.[3] But it is possible that the zone of weakness may pass away from the continent to the Comoro Islands, which are volcanic. The highest summit in the Grand Comoro, rising to 8500 feet, has more than once been active since the islands were known, the last time recorded being in 1865.

Craters exist in Madagascar, forming an almost continuous series from the south-east to the north-west or north of the island, being especially numerous near Lake Itasy (lat. 19° S.) and in the Betafo district, about fifty miles farther south. The cones rise from an upland region of ancient crystalline rocks, being

[1] The mountain was explored and ascended by Drs. Hans Meyer and Purtscheller. See *Across East African Glaciers*, chaps. iv. and v.

[2] *Ut supra*, p. 347. Also J. S. Hyland, *Min. Mitt.*, x., p. 203. T. G. Bonney, *Brit. Assoc. Report* (1885), p. 682.

[3] Ruwenzori, at the end of Lake Albert Edward Nyanza, is not volcanic, or if there are any craters on it they are small and sporadic.—Scott-Elliot and Gregory, *Quar. Jour. Geol. Soc.*, vol. li. (1895), p. 669.

mostly composed of scoria, and not exceeding a thousand feet in height. Their walls are often breached by lava streams which have flowed from the craters. These are all basalts, but "bell-shaped hummocks,"—of the type of the Puy Sarcouy, Auvergne,—composed of trachyte or andesite, also occur. Hot springs exist in places, but there is nowhere any distinct tradition of an eruption.[1]

The Amirante and Seychelles Islands probably indicate the continuation of the volcanic zone which traverses Madagascar. The former are volcanic, though apparently no vent is active. The Seychelles are coral reefs surrounding a granitic centre; but some volcanic rocks must exist, though their age is uncertain. The Mascarene Islands represent one of those comparatively short zones of weakness which seem commoner in the Pacific, and make themselves visible by piling up eruptive materials on deep parts of the ocean floor. Réunion, or Bourbon, the nearest to Madagascar, is a volcanic mass, to which reference has been already made.[2] Parts of it must be of considerable antiquity, as they are deeply furrowed with gorges. The island is hilly and rises towards the centre in the Piton de Neiges to a height of 10,069 feet, the summit of which is only a fragment, according to M. Vélain, of a huge crater; but hot springs issue in several places from the flanks. When this vent ceased to be active the focus of discharge was

[1] R. Baron, *Quar. Jour. Geol. Soc.*, xlv. (1889), p. 315; and F. H. Hatch, *Id.*, 340.

[2] Page 83.

transferred to the south-east, its gradual movement being marked by a line of cones where the Piton de la Fournaise, 8612 feet, is in constant activity.[1] The oldest vents in Réunion are described as consisting of andesites, followed by some that are serpentinous —altered basalts rich in olivine; the newer are varieties of basalt. The Mauritius also is volcanic, but without any active vents. There are some craters and crater-lakes, but in most parts the igneous masses have been greatly sculptured by meteoric agencies; two of the peaks, Pouce (2650 feet) and Pieter Botte (2676 feet), being noted for the singularity of their form. The lonely island of Rodriguez is also volcanic, its central cone rising to a height of 1760 feet, but no eruption has occurred within the period of history.

In the more southern part of the Indian Ocean are several scattered islands. The two northernmost, Amsterdam and St. Paul, forty-two miles apart, are near the 38th parallel of south latitude. The former is a plateau-like mass of lava, rather more than five miles long and three wide, rising to a height of above two thousand feet, and crowned with a number of cones and craters, mostly rather small (the greatest height reached being 2989 feet above sea-level), which are associated with flows of basalt—all this part having a very fresh aspect.[2] We may infer from its

[1] See C. Vélain, *Descr. Géol. de la Presqu' Ile d'Aden*, etc. (1878), p. 105. This vent is at the side of and a little below the summit crater of Piton Bory, and the cone which they crown rises out of a great broken crater.

[2] C. Vélain, *ut supra*, p. 332.

structure that the island has been built up by copious discharges of lava, followed by a long pause, during which the sea wore away the outer edges, as we may see in the Faroes and some of the Hebrides, and to this succeeded a comparatively recent set of outbursts, by which puys were formed.

A map of St. Paul tells at a glance the history of the island. It has been a volcanic cone, rising to a height of about 2500 feet, with a crater even somewhat deeper. The waves have pared away its margin and have cut a great slice off the eastern side, including about one quarter of the crater wall, so that the sea has gained admission into the interior. There are some small subsidiary craters, but sundry hot mineral springs and fumaroles are the only signs of its former activity. The first ejections of which any trace is visible were rhyolitic (lava and pumice). These were followed by basaltic materials, of which the part of the island above water is almost entirely formed. To the S. S. W. of St. Paul, about the 50th parallel of south latitude, is Kerguelen's Land, a large mountainous island, the central part of which, Mount Ross, rises over 6000 feet above the sea. It is mainly of volcanic origin, the rock chiefly basaltic. In the north-east and south the cones have disappeared, but an active vent is said to exist towards the south-west.[1] Macdonald's Island, or rather group, about 240 miles to the south-east of Kerguelen's Land, is apparently of similar

[1] Moseley, *Notes of a Naturalist*, chap. viii.

composition, but presents no indication of recent activity. Heard Island,[1] also south-east of Kerguelen's Land and about 300 miles away from it, so far as the snow and ice allow it to be seen, is described as volcanic (basaltic lava, and scoria), but only fragments of a crater appear to remain. Bligh's Cap and Crozet Island seem to be fragments of volcanic rock still undestroyed by the waves. Marion and Prince Edward Islands, between the 46th and 47th parallels, are also volcanic (basalt), but have also long ceased to be active.

These islands, together with those already mentioned in the more southern part of the South Atlantic, rise from the downward slope of the shelving plateau which supports the great Antarctic land-mass, being all within the 1000-fathom line of soundings and having deeper water to the north. Whether they indicate the presence of a curving zone of crust disturbance, like those which sweep along the eastern coasts of Australia and Asia, the scanty evidence at our command prevents us from ascertaining.

This enumeration is not complete. We have not attempted to do more than indicate the still active vents and some of the more important zones in which they have become extinct late in the Tertiary era. But we may say that so far as oceans are concerned this truth holds almost universally,—the smaller islands are either of volcanic origin or coral reefs. In the one case their significance is clear, in the other some

[1] *Ut supra*, chap. ix.

geologists venture to assert that even coral islands are only comparatively thin masses of organic origin erected, like a castle on a hill, upon the denuded summits of volcanic cones. This, however, remains to be proved; if it can be established, then the lines of islands in the greater oceans will also indicate the lines of volcanic vents which have been active at no very distant date as the geologist counts time.

The facts enumerated in this chapter lead in general to the following inferences:

1. Active volcanoes, with very few exceptions, are situated either on or at no great distance from great masses of water.

2. Elevation above sea-level appears frequently to be unfavourable to great activity. The higher volcanic summits are commonly extinct, or, if they continue to eject materials, these are usually only light scoria, dust, and steam. The great peaks of the Andes, for instance, seldom, if ever, discharge lava, and serious explosions are rare. While we are unable to assign any fixed limit, we may say that it seems possible for a volcano, like a human being, to outgrow its strength, and to pay for increased stature by diminished energy.

3. They have often a linear, or perhaps we should say zonal, arrangement, being grouped in more or less curving narrow bands, which extend, from one end to the other, over many hundreds of miles on the surface of the globe.

4. These zones are usually related either to great

mountain chains or to the coast lines of continents, or to connected strings of islands, or to long submarine plateaux, which separate deep oceanic basins. In the Pacific, no doubt, volcanic mountains appear to have been built up almost directly from a comparatively level floor lying at a depth of at least 12,000 feet. How far this apparent exception seriously vitiates the rule it would be premature to affirm, owing to the difficulty of ascertaining all the circumstances, but the inference is certainly true in a large number of cases.

To what conclusions these observations tend it will be our business to consider in the next chapter.

CHAPTER VI

THE THEORIES OF VOLCANOES

IN the preceding chapters we have attempted to give a summary of the principal facts relating to volcanoes: the phenomena of their eruptions, their structure and distribution, and their history to some extent in the more remote past. We now pass on to enquire whether these lead us to any inferences as to the causes of volcanic action. An eruption may be described in general terms as the discharge from underground, more or less explosively, of material which mostly is or has been in a molten condition. This suggests two questions which may or may not be satisfied by a single explanation. What produces the explosive phenomena? and what has caused the material to be molten? When an answer to these has been found, if this be possible, one or two subsidiary questions will arise regarding variations in the material and other phases in the history of an eruption.

But before proceeding further we must briefly notice—more as a matter of history—an hypothesis relating to the formation of a volcanic cone; for it

no longer requires, as would have been the case forty years ago, any serious discussion. Such a cone was once believed to have been formed, not by ejected materials heaped up during a succession of explosions around an orifice in the earth's crust, as is now universally admitted, but mainly by the elevation of strata (usually sedimentary, and owing to the pressure from below of incandescent material) in a more or less cone-like form about a central point, which ultimately becomes a vent, discharging scoria, lava, etc. The former is often called the "crater of ejection" hypothesis, the latter the "crater of elevation." If this be adopted, a volcano may be compared to a boil on the earth's crust; there is first a great swelling-up of the flesh, then, after it has "broken," a discharge of matter. According to this explanation, only the crater and the more visible part of the cone consist of dust, scoria, and lava. Could a section be made through it the beds which were older than the date of the first eruption should be seen to form the bulk of the cone, and to dip outwards from the central vent. By what means strata under ordinary circumstances could be raised and maintained in the position required by this hypothesis is not easily understood. But these objections are fully stated in the ordinary text-books, so that it is needless to waste time in discussing a notion which at the present day would not be maintained by any geologist of repute. It will be enough to say that the study of extinct volcanoes in their various stages

of dissection affords no evidence for and very much against this hypothesis. Indeed, even if, as we should naturally expect, and as has sometimes occurred, the ground is slightly uplifted prior to the first outburst, as was seen at Monte Nuovo, this is commonly more than counterbalanced by subsequent subsidence, for in an extinct volcano any upturning of the edges is usually confined to the part quite close to the vent,

(1) ON ELEVATION HYPOTHESIS.

(2) ON EJECTION HYPOTHESIS.

FIG. 18. DIAGRAMMATIC SECTION OF VOLCANIC CONES.

and the strata on the whole more often exhibit an inward dip. Thus we may regard this question as closed, and the "crater of ejection," or rather "cone of ejection," to remain in undisputed possession of the field.

We pass on to consider the first of the main questions already mentioned: What produces the explosive phenomena of a volcanic eruption, phenomena which, as has been shown, are almost universal, although they may vary much in intensity, even in the history

of a single volcano? It is obviously some agent which is strengthened by repression. Violent explosions are very rare in a volcano which, like Stromboli, is in constant activity; they are commonly witnessed in one which has enjoyed a long interval of repose, like Vesuvius prior to A.D. 79, or Krakatoa prior to August, 1883. To fasten down the safety-valve is obviously as dangerous in a volcano as with a boiler. We can hardly doubt that steam is the main explosive in the one case as in the other, though possibly other gases may to some extent co-operate with the vapour of water. A kettle as it boils over—a geyser still more perfectly—reproduces, though in water instead of in more solid material, the phenomena of a volcanic eruption. During that episode steam is discharged in enormous quantities from the crater[1]; it condenses in great cumulus clouds about the summit, and is emitted so copiously by the lava stream that this seems to smoke as it flows. Every explosion, every discharge of projectiles, is accompanied by a jet of steam, like the firing of some monstrous gun. Water is also present in every volcanic product, and lurks unseen in the rock even after that has become solid. M. Fouqué, who studied an eruption of Etna in 1865, made a number of observations in order to measure the quantity of water which was discharged from the vent in the form of steam. Each explosion, he estimated, ejected about seventy-nine cubic yards of water in this condition, and one of these occurred on an average

[1] See Plate I.

every four minutes for about 100 days. That is to say, the discharge amounted to 2,829,600 cubic yards of water.[1] Moreover, this does not adequately express the quantity emitted from the volcano, for a lateral crater was the focus of this eruption, and the one at the summit also emitted great quantities of steam.

When it is remembered that the volume of steam is nearly 1700 times that occupied in the form of water, and that the expansive force at the time of change is enormous, this seems an adequate cause for the explosions. The effects of a sudden conversion of water into steam are familiar to all, and an illustrative experiment, often quoted, was performed during an eruption of Etna in 1843. A stream of lava from the volcano had invaded the cultivated land. Many people were near its advancing front, engaged in the rescue of property. Suddenly its extremity was seen to swell up like an enormous blister, and then to burst, discharging a quantity of steam with a volley of fragments, solid and liquid. Sixty-nine persons, it is said, were either killed on the spot or received fatal injuries.[2] The catastrophe was caused by the lava having flowed over a subterranean reservoir of water, thus generating suddenly a quantity of steam that caused the explosion. If then the removal of pressure allows any accumulation of water in the lava, which has been retained in a liquid con-

[1] This would be rather more than the contents of a reservoir 4000 yards (full 2¼ miles) long, 700 yards wide, and 10 yards deep.

[2] Reclus, *The Earth*, chap. lxvii.

dition, though far above its boiling-point, to flash into steam, an explosion must result. But even if the lava be at a higher temperature than the critical point of water, as in all probability it generally is, still if it be permeated throughout by the vapour of water,

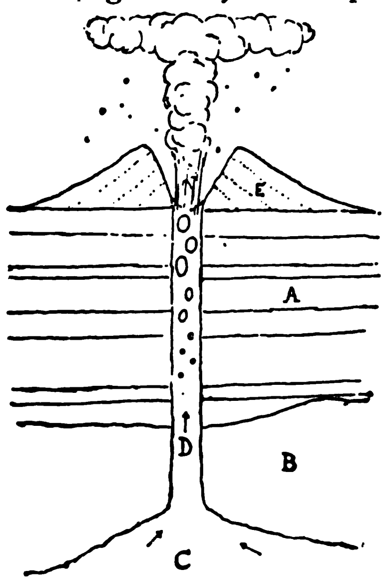


Fig. 19. Diagram to Illustrate the Supposed Action During an Eruption.

A, sedimentary rocks; *B*, crystalline rocks; *C*, supply basin of lava; *D*, lava moving up pipe, and steam bubbles gradually forming as the pressure diminishes; *E*, cone and crater.

this may gradually accumulate in the pipe as the mass is rising upwards, so as to produce a constant succession of explosions when these great bubbles of steam approach the bottom of the crater. The annexed diagram may serve to give a very rough notion of a volcano as a working machine, and the process may be illustrated in opening bottles of any effervescent

liquid. If we remove the cork very slowly, the gas forms numbers of small bubbles and passes off quietly. If we do it more quickly, larger bubbles form, especially in the neck of the bottle, which carry up a little of the fluid, the more so if this is slightly sticky. If, however, we pull out the cork suddenly, an "eruption" is the result. Thus I think it very probable that, as is the case with the Great Geyser in Iceland,[1] the actual pipe of the volcano, to a great extent if not wholly, is the seat of the explosive phenomena.

But a further question now arises, How can we explain the presence of water? In a number of cases active volcanoes are situated on islands, or at no great distance from the sea or from some other considerable sheet of water.[2] Still, the rule is not abso-

[1] See Tyndall, *Heat a Mode of Motion*, chap. iv.

[2] Sea-salt also has been observed as an efflloresence on the scoria after an eruption, as at Etna, and in Iceland; moreover, Deville and Fouqué have called attention to the fact that the volatile products given off from a volcano during an eruption are in the order which they would follow if sea-water were being decomposed at temperatures from rather below 212 F. upwards. All the ordinary constituents of sea-water, except bromine, have been observed. The late Sir Joseph Prestwich (*Geology*, vol. i., chap. xii.) attributed much importance to the access of rain-water, though not excluding that of the sea. He called attention to the fact that while in some cases the salts and other products ejected suggested the presence of sea-water, in others the evidence was opposed —as where fresh-water diatoms have been found in tuffs (Mr. Whymper disbelieves the story of fish having been ejected from Cotopaxi—*Travels among the Great Andes of the Equator*, vol. i., chap. xiii.), and he suggests that very often when a volcano is near the sea the precipitated water may first gain access by percolation, and cause an eruption; that will lower the general underground water-level in the neighbourhood of the volcano, and the effect of this will be an in-current from the sea, until the equilibrium between sea-water and "land-water," which had been disturbed by the explosive discharges, is again restored, and preparations are thus made for a new eruptive outbreak.

lute. Tolima and Cotopaxi are 125 miles from the sea, Popocatepetl and Sangai about 155 miles, the extinct crater of Kilimanjaro is not much less than 200 miles away, and the Chinese volcanoes, if we can accept their existence as established, are at least treble that distance. It has accordingly been suggested that either the sea in some way, or rain-water downwards by percolation, may make its way, and thus come into contact with the intensely heated magma in the supply basin of a volcano. The materials of a cone are undoubtedly favourable to percolation; that is shown by the length of time for which they are able to retain their form unaffected by denudation, and the amount of precipitation in the immediate neighbourhood of a volcano is often large; but some difficulties have been advanced which cannot be put aside without notice. Any hypothesis which is adopted must account not only for the continuance of volcanic action, but also for its beginning. Hence, in invoking the aid either of oceanic or of rain water, we must find for it a means of access prior to the first explosion, and must not rely too much on the conditions which exist when the volcano is, so to say, in working order. If, then, the water is obtained, more or less, from above, either by flowing downward from the sea or by precipitation from the sky, how does it make its way to the incandescent mass which is all ready for an explosion? Some have supposed that when it comes from the sea, the bed of that is fissured, and thus access is given. It is very probable

[redacted]

that those frightfully destructive explosions at Krakatoa were more or less due to inrushes of water from the ocean coming into contact with molten lava. But even in this case we must explain the beginning of the eruption, and in all we must assume some agency to be already at work, forcing the incandescent mass upwards and throwing the overlying rock into a state of violent strain. Such disturbance, as we shall see, would not be impossible, but when rupture occurs we should expect that the molten matter would be squeezed into fissures as soon as they opened; in that case, as contact with the water would be restricted to a narrow band, the explosion would be slight. In fact, this hypothesis can only be maintained on the assumption that the melted matter is already undergoing such severe pressure that it would at once leap forth in large quantities if a leak were opened.

The idea of gradual percolation, either from the adjacent ocean or from the general rainfall (supposed ordinary at first) of the district, to some extent avoids this difficulty, though even here we must assume that the lava is either forced upwards or is melted down *in situ;* the objection, however, has been advanced that as soon as steam began to form, the pressure set up by its expansion would put a stop to the advance of the percolating water. To this, however, it may be replied that water does percolate through rocks to a considerable distance, for all are more or less porous, and are invariably found, when quarried, to contain a

certain quantity of water, which must be adventitious.[1] The late Professor Daubrée[2] further demonstrated by experiment that water, separated from a chamber filled with steam at a temperature of about 160° C. by a close, fine-grained sandstone,[3] passed through the slab with ease, notwithstanding the outward pressure of the steam. Now the crust of the earth beneath a level which may be taken as very little below the ordnance datum, unless the water in some way or other be returned to the surface, must be permanently saturated. Hence, as precipitation from the sky is constantly going on, there must be either an addition to or a subtraction from the surface-level of this water-logged mass, or some kind of movement in it. If so, the water must be either withdrawn in some way or other, or returned to the surface. The former may happen in the conversion of anhydrous into hydrous minerals, because then it passes from a fluid to a solid condition, and a certain amount probably is disposed of in this way; but very much more, in all probability, is returned to the atmosphere by a

[1] This amounts in some cases to as much as two fifths of their volume, but this is an extreme instance, such as chalk; a sandstone used in experiments by the late Professor Daubrée absorbed about .17 of its volume; and Drachenfels trachyte .09. According to Delesse fine-grained granite only holds .12, and basalt .33 per 100. Probably the harder rocks hold on the average from one to two per cent. In that case the amount of contained water, speaking generally, would diminish in descending. See Daubrée, *Geol. Experiment*, chap. iii.; Prestwich, *Geology*, vol. i., p. 156; and Bischof, *Lehrbuch der Chem. Geol.*, i., p. 233.

[2] *Geol. Exper.*, vol. i., chap. iii., p. 237.

[3] That from the Vosges, used as a building-stone at Strasburg.

terrestrial respiration, as we might venture to call it, from the mouths of volcanoes. As the facility with which water found a passage in Professor Daubrée's experiments was increased by heat, so the presence in the crust of the earth of a mass of matter at a temperature above that of the surrounding parts would, as it were, attract the water from these, and thus keep up the paroxysmal action until the whole region had assumed a uniform temperature. We seem, then, justified in concluding, from the phenomena of volcanic eruptions, from illustrative experiments, and from the testimony of the rocks themselves, that the actual eruption, the intermittent, though often long-continued, paroxysmal condition, is due to water, and that its withdrawal will mitigate and ultimately put an end to this, and so to the volcano.

But may not the water be an actual constituent of the upper portion, at any rate, of the globe? This view has been supported by many authorities, among others by Mr. O. Fisher, who considers this an adequate cause of the phenomena of eruption. That water is so present can hardly be doubted, as it almost universally occurs in the small cavities of the constituent minerals of the most deeply seated rocks; and though in some cases these cavities may not be original, yet they are so in others. Still, the amount of the fluid to which they testify is not large, and as we rarely find hydrous minerals among the original constituents of plutonic masses, it is difficult to understand what has become of this associated water. So

that while we admit that water is present to a considerable depth, and regard it as very probably affecting the consolidation of a rock mass, we seem unable to account for the phenomena of volcanic eruptions without supposing a marked and local increase of the water originally present in the magma.

But the occurrence of molten rock has yet to be explained, for this obviously is the prime requisite for an eruption. In the opinion of some authors this is due to chemical, of others to mechanical, causes. The following hypothesis was advanced by the late Dr. Daubeny. The mass of the earth most probably consists of bases still unoxidised, combination with that element having taken place only in its outer portion. The globe, in fact, might be compared to an orange, the skin of which represents its oxidised envelope. But combination must be going on continuously, for water is always penetrating downwards, not only carrying with it oxygen in solution, but itself also undergoing decomposition. Thus there is no difficulty in supplying the requisite amount of oxygen. But chemical combination develops heat, and if this is taking place on a great scale it may be sufficient to melt neighbouring masses of rock.

This hypothesis, however, is open to the objection that as the process would be gradual it would be incapable of producing a great elevation of temperature; in other words, that the cause, though true, is inadequate. Another objection also has been made. If the oxygen is largely supplied by the decomposition

of water, and this seems necessary in order to obtain a sufficient amount, hydrogen must be liberated in great quantities; it would certainly be ignited, and every volcano blaze like a gigantic gas-burner. But where are the flames? was the question asked by Daubeny's opponents. These were not to be found, and on this account he abandoned the hypothesis. Since his day, however, the flame of hydrogen has been not seldom detected in a volcanic eruption; nevertheless, the quantity has been insufficient to give any real support to the hypothesis. A third objection is the large mass of material which would have to be oxidised in a very limited time to develop the heat required in eruption. In that of Etna, already mentioned, Professor Fouqué made an estimate of this, and found it would be as much as would be developed by the oxidation of seven blocks of sodium, each 100 metres cube. On the whole, then, this hypothesis seems to be unsatisfactory as a general explanation of volcanic action. Some have supposed magnetic currents to produce local melting of the rock. Such currents undoubtedly traverse the earth's crust, and melting metals in the electric arc is a familiar experiment, often of great commercial importance; but there is not evidence to show that these currents are sufficiently localised or strong enough to produce any material elevation of temperature in the rocks through which they pass. Indeed, in the present state of our knowledge, explanations of this kind are regarded with just suspicion as being only

ignotum per ignotius, a process unjustifiable in any scientific investigation.

To turn to mechanical causes, one which seemed at first sight very plausible was advanced by the late Mr. Mallet.[1] The following is a brief outline of his argument: By a series of experiments he determined (*a*) the amount of pressure which was required to crush a number of cubes, made from rocks selected as fairly representative of the materials of the earth's crust; (*b*) the amount of heat which was developed in the process of crushing. These ascertained, he applied the results to the crust of the earth. If we assume the globe to have been once an incandescent mass, the surface when the liquid first "skinned over" would have been for a time in a state of tension, and then the solid part would be constantly breaking up and probably sinking; but after a time a more solid crust would form, and as this thickened the state of tension would be gradually exchanged for one of compression. It is possible to calculate the amount of pressure which might thus be exerted, and it is expressed by the formula $T = \frac{Pr}{2}$, where T is the tangential thrust, r the radius of the earth, and P the weight of a unit of volume of the crust. From this it follows, taking one mile as the unit of length, and $r = 4000$ miles, that $T = 2000$ P, or the tangential thrust on each face of a cubic mile of the earth's crust is equal to 2000 times its

[1] *Phil. Trans.* (1873), p. 147.

weight, a pressure which would suffice to crush the hardest of rocks. The effects of this crushing, however, would be local, because it would occur along the lines of greatest weakness, and it would be more or less irregular, quasi-periodic, and paroxysmal. The amount of heat thus produced can also be calculated. Mr. Mallet estimated that if a cubic mile of the mean material of the earth's crust were crushed to powder, heat enough would be developed to raise 7.6 cubic miles of water from the freezing- to the boiling-point, or, if 2000° F. be taken as the fusing-point of average rock, to melt nearly $3\frac{1}{2}$ cubic miles of this, if it were of the same specific heat. If, then, the volume of the crust be taken as about one-quarter of the total volume of the globe,—that is to say, as a shell 400 miles in thickness,—987 cubic miles of rock (or less than $\frac{1}{65,000,000}$ of the whole) annually crushed to powder, would be equivalent to the total telluric heat lost in the same time. This undoubtedly would be much more than enough to account for the whole of the volcanic action of every sort manifested in the same time on the globe. How much more it is very difficult to say, but at the present epoch probably quite four times more than is required; so that the conversion into work of a portion of the heat lost by the globe as a whole, and the local retransformation of this into heat, owing to the crushing of the crust, would amply suffice to keep volcanoes going. The reasoning is valid, but, in questions of this nature,

Huxley's noted saying, that the value of the grist from the mathematical mill depends on the quality of the corn put into the hopper, must not be forgotten. A cube of rock, crushed in a machine by applying pressure to two opposite faces, is in a very different position from the same cube when it forms a portion of the earth's crust, acted on by tangential thrusts from four sides, and supported from beneath. Again, assuming crushing to take place, this process would be more or less gradual, the elevation in temperature would correspond with it, and the result would be that the mass, as a whole, would be kept at a lower than the estimated temperature, though for a longer time.

But the most fatal objection to the hypothesis is the total absence of any confirmatory evidence in nature. If it were true, volcanoes should be most abundant in regions where the strata evidently had been greatly compressed, namely, in regions of folding, overthrust faulting, and cleavage. But though, as we have to some extent suggested, and as will be presently shown, there is often a certain connection between such regions and volcanic action, it is not of such a direct kind as to give much real support to the hypothesis. The difficulty already stated in reference to another question also applies here. Sedimentary rocks do not, as a rule, correspond in chemical composition with the ordinary products of volcanoes, so the latter can hardly be the others transformed, while if we try to elude this difficulty by sup-

posing igneous rocks to have been thus remelted, then we only shift it a stage farther back. But, worse than this, the evidence which we can obtain by a careful study of rocks themselves, not only affords no support to Mr. Mallet's hypothesis, but is even hostile to it. Here I venture to speak with the confidence of personal experience, for probably few geologists have examined under the microscope so large a number of rocks which have suffered from earth movements and been greatly crushed as myself, and I have no hesitation in affirming that I have never seen the slightest approach to fusion in any part of such a rock. The effect of crushing does indeed seem favourable to certain mineral changes, but these are almost invariably on a microscopic scale. A granite may be crushed till its quartz is reduced to powder and its felspar is almost entirely replaced by minute mica, but it has then become only a peculiar variety of mica-schist, and has not put on the slightest resemblance to a trachyte,[1] or even to a rock of its own nature, in which some of the constituents have been locally melted by exposure to a high temperature.

Thus all attempts hitherto made to attribute volcanic action to causes merely local appear to be failures, and we are compelled, at any rate at present, to

[1] Mr. Mallet attempted to strengthen his argument by citing some instances which he supposed to be favourable, such as the fissile structure in certain phonolites in Auvergne, and the breccias intercalated with the lavas of Snowdon. In regard to these it is enough to remark that, if the paper had been revised by any competent geologist, this portion would not have appeared in the *Philosophical Transactions*.

fall back on the hypothesis that the ejected material forms part of the hot magma of the earth, even though we may admit that volcanic eruptions would not occur without the administration of an irritant, or apart from some other disturbing cause.

The supposition that lavas and other volcanic ejectamenta are samples of the material which underlies the superficial and commonly sedimentary portion of the earth's crust accords perfectly with two facts which are familiar to every student of this branch of geology: one, that no real difference exists between the products of vents still active and those from the earliest volcanoes which we can recognise in the most remote past. The older rock, no doubt, has undergone many changes; one mineral has been replaced by another, the alteration being sometimes caused by either slight addition to or subtraction from the chemical constituents; the structures may be modified[1]; but all these changes can be traced and explained: they are merely the inevitable results of time, and no more destroy the personal identity of a rock, as it may be termed, than the results of extreme old age do that of an individual. The most ancient volcanic rocks known to us in the British Isles—such as those of the Wrekin or of Llanberis—must have been in their day obsidians, pitchstones, or rhyolites, just like those of modern volcanoes. The other fact is this: that the materials ejected can be classified into a certain number of species, or at any rate can be shown to range within certain rather

[1] As, for instance, by the process called devitrification.

definite limits of composition, while their distribution and general sequence suggest that they have been supplied from a source such as we might expect to find beneath the crust of the globe.

The last statement will require to be considered in some detail, for it involves more than one rather wide enquiry. Assuming, as we are justified in doing, the inner parts of the globe to be much hotter than the surface, and the temperature to rise in proceeding downwards, we must endeavour to ascertain that of the lava at the time of discharge. We can thus estimate, from the known law of increase, the approximate depth from which the lava has probably come. Should it be so great that we cannot imagine any general cause capable of bringing this lava up to the surface, we shall be compelled, at any rate with our present knowledge, to look for some cause which either can produce a local elevation of temperature or can locally intensify the pressure at a more deeply seated portion of the crust.

To determine the temperature of the lava at the time of emission is obviously not easy. Still, enough has been ascertained to enable us to form a fair idea. Experiments made at Vesuvius in 1855 showed that the lava was still moving at a temperature of barely 1228° F. But on another occasion lava from the same volcano fused silver, the melting-point of which is about 1870° F.; and on a third a piece of copper wire, which indicates a temperature not below 2204° F. The lava in the crater of Kilauea is often observed

to be at a white heat, which would mean a temperature approximately of 2400° F. Recently, however, some more precise experiments have been made at Etna by Signor Bartoli.[1] He obtained the following temperatures near to the source and at a depth of one metre in the flow, viz., 1940°, 1814°, 1796°, and 1778° (Fahrenheit). From this we may infer that the loss of heat is at first rather rapid, and that the temperature at emission is commonly not less than 2000° F. It will be obvious from what has been already said that some lavas are much more fluid, that is, *ceteris paribus*, hotter, than others; but the observations quoted above show that in any explanation we have to account for a temperature of at least 2000° F. at emission. Some heat also would be lost in transit from below to the surface; the amount, however, of this probably would not, as a rule, be large. Still, it would be sufficient to prohibit us from adopting any figure lower than that just given for the temperature of the lava when it began to move upwards. As the average increase of temperature from the surface in a downward direction is approximately 1° F. for every sixty feet, we may presume the required temperature to exist at the depth of about 120,000 feet, or about 22½ miles.[2] Thus we may conclude that unless we have assumed

[1] "Sulle temperature delle lave (Etna)."—*Boll. Mens. delle Accad. di Sci. in Catania*, N.S. (1892), p. 2.

[2] The surface temperature is neglected, since a precise result could not be obtained under any circumstances. If we take 1° for every 64 feet (the estimate preferred by the Committee of the British Association, *Report*, 1882), the depth would be a little more than twenty-five miles, or $\frac{1}{160}$ of the earth's radius.

too slow an increase of temperature, and that seems hardly probable, or some other disturbing causes intervene, the lava is generally supplied from a zone situated at a depth of from twenty to twenty-five, or possibly to thirty miles, in the crust of the earth. Hence it follows that the force which lifts it to the surface must be one which can be operated at this depth.

We pass on to enquire how far volcanic products, by their distribution in space and time, and their sequence in eruptions, support the idea that they have been forced upwards from beneath the more solid crust of the earth. We may assume for the moment that if the latter has cooled down from a liquid condition, its materials (underneath the comparatively superficial layer affected by denudation) should exhibit some kind of stratification, by being arranged in the order of their specific gravities, the lighter of course being at the top. Hence we should anticipate that the materials discharged would be nearly identical in character throughout a region where the events were likely to be connected, and would exhibit a sequence in time. We should expect that at first the lighter materials would be ejected, and that as the fissure deepened and the way was cleared, these would be followed by the heavier; or that, in some cases, since the more acid substances generally become solid at a higher temperature than the more basic, the latter only might be discharged, because the former had already ceased to be liquid. In like manner, as the temperature in the earlier ages of the earth's history

probably increased in descending more rapidly than it does at the present time, we might anticipate that acid lavas would be more common among the older formations, and basic among the later.

How far, then, are these expectations confirmed by actual observation? In the first place, as already stated, the only differences between ancient and modern lavas are those produced by the lapse of time. Still, so far as our present knowledge goes, basic kinds do seem rarer among the very ancient lavas. In Great Britain the most ancient lavas are distinctly acid—rhyolites and dacites; these continue common, though andesites also make their appearance, till the end of the Ordovician period—while anything like basalt is certainly rare. In Old Red Sandstone times andesites are also common, but it is not till the beginning of the Carboniferous period that basalts become abundant. So far as I can ascertain, there is nothing exceptional in the result of the British evidence.[1] In Tertiary and post-Tertiary times the variety is great, acid, basic, and intermediate rocks being all represented, though the first are not very abundant in active volcanoes.

Assuming that lavas (with their associated fragmental materials) represent magmas which exist beneath the outer crust of the earth, we find on ex-

[1] It may have some significance, though these rocks are more or less deep-seated, and so cannot be precisely dated, that representatives of acid groups of rocks are common in the Archæans. The huge masses of "norite" in Canada are almost the only important exception to this rule, and these, so far as I know, are intrusives.

amination that the chemical composition, on which, subject to effects of environment, the mineral constitution of igneous rocks depends, varies within certain fairly definite limits. In the most acid kinds the silica percentage will be about 75 (sometimes even rather higher); the alumina about 14; the alkalies—potash or soda, or both—about 8; while ferric and ferrous oxide together are about 1.5, and generally do not exceed 2.0; and neither lime nor magnesia rises above 1 per cent. From the number just given the silica percentage falls steadily to about 40 (though under 45 is exceptional), and as this falls the iron-oxides, the lime, and the magnesia rise (though now one, now the other, may dominate), so that at last their united value may amount to nearly one-third of the whole material, and even more if the ferric oxide be added. The alkalies fail, but not quite uniformly with the silica; for while the percentage declines in the more familiar kinds of rock, it is fully maintained, indeed sometimes is rather increased,[1] among certain outlying and not common groups. At first the alumina increases with the fall of the silica, so that when the percentage of the latter is about 60 that of the alumina is about 17. It runs up even higher in some of the outlying alkaline rocks just mentioned, in which, generally speaking, the silica percentage is rather under 60, so that it may slightly exceed 20; but in the ordinary kinds of rock we may expect, when the silica percentage is about 50, to find that of the

[1] It rises to about 11 or 12 per cent.

alumina very little under 20. Here, however, the protoxide bases are beginning to rise rapidly and the alkalies to fall, so that they may have already dropped to about 3 per cent. Then when the silica is approaching 45 the alumina commonly drops rapidly, and is associated with protoxide bases instead of with alkalies.[1]

Next, as to the geographical distribution of these rocks. We find, as has been already shown in several cases, that commonly during one and the same geological epoch rocks very similar, sometimes identical in chemical composition, have been ejected over rather extensive areas of the earth's crust. Though the porphyrites of the Lower Old Red Sandstone in Scotland vary considerably, yet a large number of them exhibit a strong family likeness. Basalts were copiously discharged during a Tertiary epoch over a zone extending from Antrim to at least the north of Skye—that is, well over 200 miles in length. In reality the distance was much greater, and possibly it reached even as far as Western Greenland.[2] The volcanic rocks of the Andes from one end of South America to the other, so far as is known, are very closely related, the lavas, with few exceptions, being andesites or dacites.[3] Those also of the great mountain region of Western North America, from British Columbia to Mexico and Central America, are closely related

[1] The peridotites have very little alumina, and practically no alkalies; but, as already stated, I do not include them among the volcanic rocks, because at present we do not know that they ever reached the surface.

[2] See pages 180, 230.

[3] See pp. 246–250.

to those of the Andes, though, perhaps, they exhibit rather more variety. Nevertheless, the Tertiary and post-Tertiary volcanic materials on the western side of the two Americas, taken as a whole, form a group with common characters throughout. A region thus distinguished either by the presence of some one or more well-marked rock species, or by a definite succession of recognisable varieties or species, is called a petrographical province. But this is by no means the only example of such a province. Rocks rich in alkalies (especially soda), and rather poor in silica (*i. e.*, in which nepheline and sometimes leucite are frequent constituents), characterise the Eifel, and an area of greater extent on the eastern bank of the Rhine; similarly nepheline trachytes or phonolites are abundant in Bohemia. Leucitic rocks make a geographical province of Central and Southern Italy, though Etna discharges ordinary basalts.[1] The Permian and Triassic ejections on the southern flank of the Alps have a common facies, and the same rule holds good elsewhere,[2] though now and again two provinces seem to have established rival volcanoes in proximity or occasionally to have overlapping boundaries.

[1] Leucite has been recently observed in the lavas of Etna, but it is a rarity.—*Brit. Assoc. Rep.* (1888), p. 669.

[2] It is also true of the more coarsely crystalline intrusive rocks, which in many cases are obviously connected with volcanic discharges, and so may be fairly mentioned in this connection. The rocks of the Christiania region, as Professor Brögger has shown, form a province, and those of Eastern America, North and South, are characterised by strongly alkaline minerals.

But, in addition to this general demarcation, changes are perceptible in the rocks within a single geographical province. Sometimes the chemical composition gradually alters as they are followed in some one general direction. Thus, in the above-named North American province a gradual increase in the amount of alkalies is perceptible in going from west to east, leucite, nepheline, alkaline-felspars, and varieties of ferro-magnesian minerals containing these constituents making their appearance. This rule, according to Professor Iddings,[1] holds in Montana, Wyoming, Dakota, Colorado, and Texas. But still more commonly an order of succession can be observed. Thus, according to the same author, we find that if the rocks be arranged according to their silica percentage, both in the Yellowstone Park and in the Neapolitan region, they occur in the following order.[2] :—

SiO_2.	YELLOWSTONE PARK.	SiO_2.	VESUVIUS AND ISCHIA.
48–55	Basalt.	46–55	Leucitic Basalts.
52–62	Pyroxene-andesite. Hornblende-andesite.	55–62	Trachytes.
64–68	Hornblende-mica-andesite. Dacite.	.. ..	
70–75	Rhyolite.	69–71	Rhyolite.

In the district about the Lago de Bolsena the leucitic rock, as at Vesuvius, was preceded by some of a trachytic character. The Tertiary eruptive rocks

[1] *Jour. of Geol.* (Chicago), i., p. 838.

[2] In this and the other lists the first-named is the most r

(beginning in the Miocene period) of the Sierra Nevada came in the following sequence[1] :—

Acid—Rhyolite (lavas and ashes).

Basic—Basalts (perhaps only lava).

Intermediate—Hornblende- and pyroxene-andesites (chiefly ashes, etc.).

Intermediate to acid—Fine-grained pyroxene-andesites (lavas only).

Basic—Basalts of various kinds (lavas only).

According to Professor Brögger,[2] the classic district of Predazzo in the Southern Tyrol, if we include the holocrystalline and more deep-seated rocks, which most probably, at any rate in some cases, sent forth offshoots which reached the surface, exhibits the following order of succession :—

Partly basic, partly intermediate—Dykes, some of the less basic being phonolites.

Acid—Represented by the red granite of Predazzo and perhaps by veins of aplite.[3]

Intermediate—Dykes and lavas (with the monzonites, their deep-seated equivalents).

Basic—Basaltic lavas with corresponding gabbro, diabase, etc.

Basic—Tuffs, lavas, etc., including the so-called augite-porphyry and melaphyre, with dykes.

The existence of an order of succession among vol-

[1] H. W. Turner, *Jour. of Geol.* (Chicago), iii., p. 385.

[2] *Die Eruptivgesteine des Christiania-gebietes*, ii., 163.

[3] With this are classed the granites of Brixen and Cima d'Asti, and it is suggested that the tonalite of the Adamello may come between this and the next group.

canic discharges was first signalised by Baron von Richthofen after a study of the rocks of Western America. He asserted[1] that they had been ejected in the following order:—

Propylite }
Andesite } —Eocene and Miocene.
Trachyte—Miocene and Pliocene.
Rhyolite—Pliocene and Pleistocene.
Basalt—Pliocene to recent.

It is now known that propylite is only a somewhat altered andesite, so that the first term may be dropped; the difference also between andesite and trachyte is not very great, so that the succession in California and Nevada may be stated in general terms (in ascending order) as intermediate, acid, and basic. This order is found to hold not infrequently, acid commonly preceding basic,[2] but itself being occasionally introduced by intermediate lavas; the basic, if the history of eruption be nearly at an end, being sometimes followed by local discharges of a variable character; here acid, here intermediate, here basic.

Captain Dutton, in a very suggestive essay,[3] has called attention to two factors which cannot fail to be of prime importance in regard to discharges from a subterranean source. These are the specific gravity and the fusion-point of each rock. The more weighty

[1] "Principles of the Natural System of Volcanic Rocks," *Mem. Californ. Acad. Sci.*, vol. i., part iii. (1867).

[2] In the Western Isles of Scotland the order of succession, as stated at page 183, is still a matter of dispute.

[3] *Geol. of High Plateau of Utah*, p. 131.

a rock the greater force is required to lift it to the surface; the more fusible, the more easily it assumes or can be kept in a molten condition, and can be moved by pressure. The fusibility may be taken, for general purposes, as depending on the silica percentage, increasing as it decreases; the weight is readily ascertained by experiment. Captain Dutton has arranged the ordinary volcanic products in such a way as to exhibit a curve of weight and a curve of fusibility. The diagrams have been a little needlessly complicated by one or two subdivisions of dubious value, as by distinguishing propylites from andesites, but the general principle is not affected by the omission of these. It is represented in a graphic form by the curves, but it also admits of a verbal statement, namely, that if we take for a standard of reference a rock of intermediate character, both in specific gravity and fusibility, such as andesite, which assumes a molten condition at a particular temperature and requires a certain amount of force to lift it to the surface, then, if the temperature remain constant, the pressure must be increased in order to lift rocks of a higher specific gravity than andesites; while if the pressure remain constant the temperature must be raised before rocks of a more silicious character than andesite could be moved, for otherwise they would be in a solid condition. Hence, if the pressure be constant, a basalt can only be got to the surface by raising it to so high a temperature that the specific gravity of the molten mass is reduced to that of an andesite which is near

the point of solidification; while a rhyolite, when once its melting-point is reached, can be brought up with little trouble.

These theoretical conclusions on the whole accord fairly well with the results of observation. Basaltic lavas very commonly are poured out in long streams, or flood wide areas, and present every appearance of having issued in an extremely liquid condition. That is the case on the plains of Idaho or the plateaux of the Outer Hebrides; the inference is confirmed by the narratives of the lava-flows from Skaptár in 1783, and in the Sandwich Islands in 1840 and in 1880. Photographs of the last-named eruption represent the lava flowing as freely as molten iron at its issue from a cupola furance. For this to happen, the basalt-magma must have been raised to a temperature far above its melting-point. But the trachytic lavas seldom make streams of great extent, and in not a few cases appear to have welled up in such a pasty condition that they have become solid almost immediately, forming sometimes dome-shaped masses, as in Auvergne.[1]

Though heat may not be the only cause of the liquidity of lavas, it must obviously be the principal one, so that for the moment we will leave any other out of consideration. If the lavas represent portions of the earth's magma, and if the more basic, as a rule, are found to be at the higher temperature, they may be reasonably supposed to represent a layer more

[1] Page 117.

deeply seated than the acid group. Passing over for a moment any attempt to account for this arrangement, and assuming that the lava is primarily forced up by pressure, let us enquire how to account for the suces-sion of materials. This pressure is generally attributed, directly or indirectly, to the contraction of the globe in consequence of loss of heat. Although there is still considerable doubt as to the exact amount by which the volume of a rock is diminished in passing from a liquid to a solid condition, and that probably depends to some extent on whether this condition is glassy or crystalline,[1] there can be little doubt that there is diminution, and this certainly continues in the cooling of the solid. As the igneous rocks, at any rate after solidification, are bad conductors, this cooling would be most rapid in the outer layers. These, as they shrank, would compress the inner mass and themselves would be in a state of strain. If, then, we fix our attention on two concentric shells (Fig. 20), the material in the outer one will be in a state of tangential strain, while that in the inner one may be exposed to tangential thrusts, and between the two a zone must exist towards which each steadily diminishes, and in which there is neither strain nor thrust. What will be the condition of the material in this zone, whether fluid or solid, we can only conjecture ; but suppose we assume it, for purposes of illustration, to correspond approximately with the limit between the two states : then

[1] There is some evidence to show that crystallisation is associated with decrease of volume.

the solid part will be strained and ruptured, the fluid one compressed. Hence, whenever a fissure extends down to the liquid interior, this will be squeezed into it, and a steady flow of magma will be set up till the pressure on the surrounding mass has been temporarily relieved. The neutral zone must gradually descend with the loss of heat. Suppose that at first it lies in

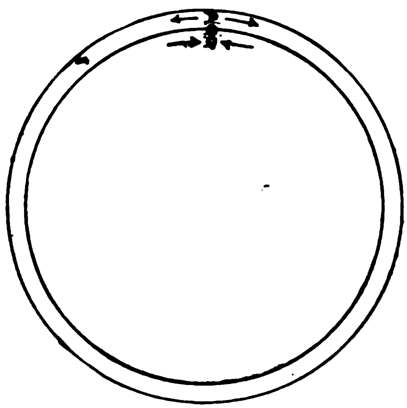


FIG. 20. STRAIN AND THRUST.
P, zone of tangential strain; *O*, neutral zone; *Q*, zone of thrust.

the acid zone so that some rock of this character may be exposed to pressure; then if this were liquid, since the fissures in the overlying mass would not extend beyond the neutral zone, acid materials only could be forced up to the surface. But with the loss of heat the thickness of the solid crust must increase; then the acid materials gradually become incapable of flowing, the neutral zone descends, and the fissures presently begin to tap the more basic layers. In this case the order of succession should be first acid, then interme-

diate, then basic rocks. So sometimes it is, but exceptions are not infrequent. As a rule, however, the earlier discharges are less basic than the later; but if two great series of discharges have occurred, separated by a marked interval of time, the one is often distinctly acid and the other no less distinctly basic, without any representative of an intermediate condition. This, perhaps, may be due to the first effusions having so far relieved the pressure that a long time elapsed before the process could be recommenced. In the language of the old legend, the imprisoned giants were

FIG. 21. FISSURES TAPPING DIFFERENT LAYERS AS THEY RUN DEEPER. *A*, Crust; *B*, Acid layer; *C*, Intermediate layer; *D*, Basic layer. 1, first set of fissures; 2, second set; 3, third set.

so thoroughly exhausted by their efforts to break loose that it took them a long time to recover their strength. During that interval the zone of intermediate rock may have become solid, as well as the overlying layer, so that the next group of fissures ran right down through it into the basic material.

But it will be urged that this explanation could only apply to a very early stage in the earth's history, because at the present time, and probably for a long way back in geological history, the outer layers in the solid portion of the globe are not in a state of tension, but of compression, the inner one (at any

rate for over 100 miles) being in a state of strain. Between the two is again a neutral zone, one of "no strain.[1]" I think, however, that the same method of reasoning might sometimes be applied—as, for example, when elevation was taking place over a broad zonal area, so as to form a low, flat arch, and locally to exclude the effects of crustal thrust. At a depth even of six miles the temperature would be about 600° F., and if some other cause co-operated to produce a considerable further elevation, the outer layer might crack, the inner, more plastic layer, might be squeezed into the fissure, and melt there in consequence of a temporary relief from pressure, and then be forced upwards by the pressure of fresh material coming from below. Further study of the distribution of intrusive masses which exhibit this succession will show whether they are connected with broad zones of upheaval, rather than with lines of sharper folding, and thus supply a test for the hypothesis.

But the topographical distribution, and the succession of volcanic and igneous rocks in a petrographical province often cannot be explained by so simple an hypothesis as that of a magma gradually increasing in basicity with its depth from the surface and the tapping of successive zones, as that of "no strain" carries the fissures deeper and deeper into the crust as it descends. We have to explain tendencies to

[1] We are indebted to Mr. C. Davison for an investigation of this problem (*Geol. Mag.* (1889), p. 220; *Proc. Roy. Soc.*, lv. (1894), p. 141). He estimates the zone of "zero strain" at the present day as about five to six miles from the surface.

mineral change exhibited by effusive or intrusive rocks as we proceed from a centre of discharge towards the periphery, or from some one point to another, or the occurrence of a more or less varied succession of discharges. We have also to account for the fact that sometimes volcanic outbreaks occur in a region either after an extremely prolonged period of repose, or where nothing of the kind has happened within the limits of historic geology. For instance, there seems to have been no outbreak in the Snowdonian district between the end of the pre-Cambrian era[1] and the Bala group of the Ordovician period (though some distance to the south great outbreaks occurred in the Arenig); and in the Eifel, though the plateau consists of Devonian rock, there are no signs of any volcanic outbreaks till late in the Tertiary era.

More than one explanation has been offered of these variations and anomalies. Some have suggested that the igneous material in its upward course has encountered rocks of different mineral composition (usually sedimentary) and has melted them down, thus altering the chemical composition of its magma. The possibility of this cannot be denied, but it is a question of the temperature of the magma and the fusing-point of the rock which is encountered, and such evidence as we can obtain by direct study of igneous rocks points to its being a rare occurrence. A large mass of intrusive igneous rocks at a high tem-

[1] Or, as some would say, the very beginning of the Cambrian period.

perature undoubtedly produces great mineral changes, especially in sedimentary materials. Now and again chemical changes also seem to have occurred in both the one and the other near the surface of junction, as though the one had taken something from the other, or constituents had been exchanged; but, as a rule, only a very limited zone in either is thus affected, and any such result can be hardly, if at all, detected in those rocks which we should consider to be truly volcanic. In some cases local melting down of a crystalline mass with a low fusion-point by another, where this is higher, may be observed, but that also, so far as our present knowledge goes, does not seem to be a common occurrence; while in ordinary volcanic rocks, such as basalts and trachytes, whether occurring in flows, dykes, or small bosses, fragments of various sedimentary and igneous rocks are by no means rarities, which are often but little altered, and usually show no signs, even under the microscope, of any fusion at the edges.[1] The possible case of a liquid magma meeting with another in a more nearly solid but not yet crystalline condition will be noticed presently.

Accordingly we seem compelled to look for causes which would operate, speaking generally, either before the magma commenced its upward journey or, in cer-

[1] In a paper contributed to the *Proc. Geol. Assoc.*, vii., p. 110, I gave a list of instances which I had seen before 1880, and I could now considerably enlarge it. In regard to the action of one igneous rock upon another, it must be remarked that the fusion-point depends not only on chemical composition, but also on crystalline condition.

tain cases, upon large masses of it which had been arrested after some progress from their original position. We have to explain why, in a long series of discharges, the first so commonly seem to have been supplied by an intermediate magma, the next by an acid one, and the third by a basic; why, sometimes, in a connected group of discharges, not inconsiderable variations are exhibited in the chemical composition of the material; why, at one time (more especially in a large mass or group of masses of igneous origin), the outer part is more basic than the inner; and why at another (this seems to be of rarer occurrence, and to be more usual in dykes) the outer zone is more acid than the interior portion. In other words, no hypothesis will be satisfactory which will not explain apparent—and these not infrequent—exceptions to the general rule.

The subject, more especially of late years, has engaged the attention of many geologists.[1] Our limits forbid any attempt at an historic sketch of the discussion, and it must suffice to state that in the chief opinions which have been maintained there is a general agreement that the phenomena must be explained by some kind of separation in the original magma. This is commonly called differentiation, and the following explanations have been offered of the process and of its cause.

[1] Excellent critical sketches of the views which have been expressed will be found in a paper by Professor Iddings, *Bull. Phil. Soc. Washington*, xii. (1892–84), p. 89; and one yet more recent by Professor M. Lévy, *Bull. Soc. Géol. France*, 3 ser., t. xxv. (1897), p. 326.

The one referred to as Soret's Principle may be thus stated. He demonstrated experimentally that, if a tube be filled with a solution of a salt and the two ends be kept for some time at different temperatures, the fluid at the colder one will become richer in the salt, or, in other words, that the specific gravity of the fluid in the tube is no longer uniform, but increases from the warmer to the colder part. Applying this principle to a cooling magma, we should find that the more basic constituents gradually separated themselves from the more acid and became concentrated in the colder parts, so that the specific gravity of the mass increased in the opposite direction to its temperature. Suppose, then, a large mass, intruded at first in a homogeneous condition, to be maintained for a rather long time at a temperature higher than that of solidification, its peripheral part should gradually become more basic than the interior; or, in the case of a molten zone in the earth's crust, the upper or cooler part should become more basic than the lower. In the latter case, obviously a heavier material would be floating on a lighter, a thing possible enough with an imperfect fluid. This hypothesis, however, presents a difficulty which will also confront us in another explanation.

That one assumes the heavier minerals to be the first to crystallise out of the magma, as is generally the case. That reduces the specific gravity of the latter, for the process obviously makes the residue more acid. These minerals accordingly ought to settle

in the fluid, as mud does in water, so that in this case we should have a more acid floating upon a more basic magma. This process would be perfectly normal, and the fact that the lower part of a lava-flow is occasionally rather more basic than the upper gives some support to the hypothesis. Moreover, if, as already mentioned, we may assume the fissures to deepen as a mass is cooling, this hypothesis explains why a discharge of acid material is often followed by one of basic. But the action here obviously is the opposite to that required by Soret's Principle, and both, but especially the latter, present the same difficulty, namely, that in either case concentration is most likely to occur when the magma is assuming a viscous or pasty condition; and thus molecular movement, except on a very limited scale (as in the crystallisation of the mass), is becoming extremely difficult. Both hypotheses seem only applicable when the mass is at a very high temperature, and in such case the latter would seem to be necessarily excluded. If, however, we suppose it to apply, not to actual crystallisation, but to a differentiation of molecules in a mass thoroughly fluid (and that such differentiation does occur in truly fluid mixtures cannot be denied), there seems no reason why a separation from gravitation should not happen in a magma.

On the assumption that a differentiation of material, whatever be the exact cause, does occur, the following explanations have been offered of some of the

anomalies exhibited in a series of volcanic discharges. The general succession is due to a differentiation in a very large mass of primitive magma. After this has occurred representatives of the segregated portions are forced (presumably by pressure) into new positions, where communication with the surface becomes more easy. But the process of differentiation still goes on, so that each of these becomes heterogeneous, and thus, if successive or different parts of either are tapped (in consequence of further earth movements), lavas of different composition (within limits) are discharged.[1]

We have assumed, as a matter of convenience, earth movements—in other words—pressure, to be potent agents in causing molten rock to change its position, but some justification for this must be shown before we finally quit the subject. Another tacit assumption, however, requires a brief preliminary notice. We have spoken (also for the sake of simplification) as if the fusing-point of a rock depended solely on its chemical composition, using the phrase in its more popular sense. The fusing-point of a crystallised mass, as already stated, will not be the same as that of a glass of identical chemical composition, but on this matter we need not dwell, for we are now referring to magmas in which little, if any, mineral separation has occurred. Will the fusing-point of these be identical with that of the glass? We seem justified in answering in the negative. We have seen

[1] Of course this holds equally good of molten material which does not reach the surface.

that a large quantity of water is present in volcanic discharges. Though much of this may have been added at a late stage in the history, and have become, as described in a former chapter, the irritant to which the paroxysmal character of the eruption is due, yet water may also have been present in the magma from the very first, or may have gained access to it at a much earlier stage in its history. This water alone will affect the fusing-point. We owe to the late Professor Guthrie the establishment of a principle which, as elaborated by Lagorio and others, has a most important bearing on the history of igneous rocks. The first experiments were made with nitre dissolved in water. Guthrie found that when this solution was of a certain strength it solidified as a whole, and that the freezing point of the compound was lower than that of either of the constituents. This he called a cryohydrate, and any such compound he proposed to name a eutectic[1] compound. Again, he found that if there was an excess of either nitre or water in the mixture then that constituent crystallised out, as the temperature fell, until the solution had arrived at the eutectic proportion, when it at once became solid as a whole. An extension of his experiments led to the conclusion that "fused mixtures are strictly analogous to aqueous solutions."[2] Such mixtures of

[1] Readily melting, from the Greek εὐτήκτικος.

[2] Teall, *Petrography*, p. 395. A summary of conclusions is given in the following pages of this work, which, however, we do not quote, because they have more bearing on questions of the order of formation of minerals than on the general one which is now before us.

silicates, as shown by Bunsen, Benrather, Lagorio, and others, behave generally as aqueous solutions, but differ from them in still maintaining a high temperature of solidification (though that is lowered by the presence of the water), and in the readiness with which they form a glass, when cooled, instead of a crystalline mixture; this latter feature probably being due, as Mr. Teall observes, to the readiness with which they become overcooled.[1] If, then, a magma contains an excess of certain constituents capable of forming a particular mineral, then, as the temperature is gradually lowered, that mineral will crystallise out until the eutectic proportion is reached, when the residue will solidify as a whole, either in a glassy or in a crystalline form. Obviously this gives a key to the explanation both of porphyritic structures and of anomalies of succession in the mineral constituents of an igneous rock of any kind; but we must refrain from any further discussion of this question, as it would lead us beyond the limits of our present subject.

Returning, then, to the main question, we may point out that if a magma can remain liquid at a temperature below the freezing-point of its other constituents in consequence of the presence of water, the access of water to a magma which is nearly or wholly waterless must result in rendering it more fluid. The water would produce the same kind of effect that aluminum, even in small quantities, does on molten iron in a

[1] *I. e.*, attain a temperature below the freezing-point without actually solidifying.

20

pasty condition, so that a mass of magma practically solid might become, owing to the access of water, so fluid as to be easily moved.

We may add that the freezing-point of a liquid is affected by pressure. If it expand in becoming solid, the assumption of this condition is retarded by pressure; if it contract, then the process is accelerated. In igneous rocks, apparently, the change in volume depends very much on whether the magma assumes a glassy or a crystalline condition, so that with our present knowledge it would be safer to say no more than that liquidity in magmas is affected by pressure. If, then, their freezing point is raised or lowered, as the result both of this and of the quantity of water present, we can understand that a magma may become sometimes solid, sometimes fluid, as either the one or the other, or both simultaneously, are varied. The increase of temperature in a direct ratio with the depth is a law which may not hold at any great distance from the surface, and it may be becoming appreciably slower at a depth of from twenty to thirty miles.[1] The loss of heat also is probably much less rapid at quite moderate depths, so that a zone may maintain nearly the same temperature for a very long time, when measured by years. In short, while we cannot venture at present to speak with any certainty, the supposition that a considerable zone in the earth's crust, at a distance of a few miles from the surface, is either just

[1] At a depth of eighty miles the law of change would be 1° F. for 141 feet of descent (Kelvin).

solid or in a highly viscous condition, with an environment now and then liable to variation, on the whole seems best to accord with the phenomena and with theoretical probabilities.

Mr. O. Fisher[1] finds a solution of many of the difficulties mentioned above by assuming that a liquid zone exists in the earth's crust at a depth of about thirty miles, and that the limits of this are affected by more than one cause. The boundary between overlying solid and underlying fluid may be depressed by the chilling due to the removal of the exterior of the former by denudation, it may be raised by deposition of sediment upon the upper surface. But a more potent disturbing factor is the folding of the superficial portion of the crust. In the process of this, one part of any band which formerly was at a certain radial distance from the centre of the earth is now pushed upwards, while another is brought nearer to that and plunged downwards into the liquid stratum. Here it is melted, and if the portion thus introduced be of sedimentary origin the absorption of this will modify the composition of the adjacent magma. Mr. Fisher has been led to adopt the hypothesis of a liquid substratum and the melting off of "the roots of mountains," because contraction of the crust from loss of heat, taken by itself, seems to him inadequate to explain the extensive folding which has occurred in it, unless we can assume the presence of a readily yielding subjacent mass. Also it explains the fact

[1] *Physics of the Earth's Crust*, (chap. xxi. more especially).

that the plumb-line is not so much deviated by a great mountain mass as we should expect to be the case if that were wholly solid. But we may doubt whether sedimentary rock would often arrive at such a depth, so that the melting would probably be confined to igneous material[1] which though solid was still at a high temperature, and it would not differ much from the magma in chemical composition.

Perhaps it is safest to say that Mr. Fisher has succeeded in pointing out more than one difficulty in hypotheses to which many incline, but whether he has found an adequate general solution must be left for time and further investigation to determine.

We are compelled, as already said, to assume the existence of pressure, in some form or other, in order that the molten material may be brought up to the surface. The expansive force of steam, as we have pointed out, is an important agency in many cases; but this probably becomes more potent when the mass is coming near to the surface, and is a prime factor in the explosive phenomena. We seem to require in addition, indeed as anterior agencies, forces to squeeze or to push the magma from place to place in the crust. The not infrequent, steady, and, for a time, continuous flow of lava from a fissure, and its intrusion as sheets, laccolites, etc., suggest that the fluid mass is forced outwards, as we can squeeze oil-paint gradually from a compressible tube. Volcanoes, as we have

[1] We have already pointed out that evidence of the fusion of sedimentary rock is rarely obtained. Page 299.

already pointed out, are commonly in connection with either mountain chains or continental coasts, or continuous groups of islands, or large and elongated submarine banks; in other words, with the upbending of land in some way or other. In the first case the area in question has undergone more acute disturbance than in the other three. A mountain chain, as a rule, consists of a more or less complicated system of folds, frequently associated with great thrust-faults, the results of overfolding and extreme strain. Volcanoes sometimes either form the actual crest of the chain, as they commonly do in the Andes, or are associated in it with peaks of more ancient rock, as in the Caucasus; but the outbreak more usually takes place along, or parallel to, the flanks. The results of compression, such as would be produced by a zonal contraction in the earth's crust, have been more than once studied experimentally, among others by Favre, H. M. Cadell,[1] and still more recently by Bailey Willis.[2] The superb monograph by the last-named author, with its numerous illustrations, enables us to understand how the underlying plastic magma is exposed to thrusting-pressures, or squeezed so that it is forced up, broadly speaking, into the apex of the principal flexure; how opportunities are afforded it of flowing out through fractures (occasionally at this apex but more frequently nearer to the datum line) which probably will extend for long distances parallel to the gen-

[1] *Trans. Roy. Soc. Edin.*, xxxv., p. 337.

[2] *Thirteenth Ann. Rep. U. S. Geo. Sur.* (1891–92), part ii., p. 211.

eral strike of the folds; how complications may be introduced by inequalities in thickness and strength in the harder and upper materials. These complications are so numerous that it would be impossible to attempt to discuss them in this volume, and we must content ourselves with stating the general fact, and referring the reader to the fine series of illustrations in Mr. Willis' memoir. Another observation points in the same direction, that volcanoes in the neighbourhood of coasts generally occur where the sea deepens with comparative rapidity. Thus they are absent from the eastern side of the American continent, but are abundant on the western; in other words, they are likely to be situated on the steeper flank of an arch. Their frequency in chains of islands or on long submarine banks also points to upheaval, though without folding. In these cases the conditions would resemble those pictured in the diagrams of Cadell and Willis, which represent the earlier stages in compression, when a broad undulation like a very low, flat arch is formed. By such an uplift a zonal strip of crust would be brought into a state of tolerably uniform strain, so that groups of parallel cracks would be opened and discharges take place from almost any part of the surface. Such conditions (which, of course, might sometimes occur, not only at the first, but also at the last) would be very favourable either to the formation of sporadic groups of volcanoes or, when the cracking was carried rather farther, to fissure eruptions.

When a comparatively slight bending, such as causes the formation of a broad anticlinal arch, has produced fissures, the lava may be forced up in these merely by the weight of the superincumbent rock. Suppose a mass in a solid condition to rest upon a zone in a more or less pasty state. The latter, of course, bears the weight of the former, and so long as the upper one is unbroken no movement will take place in the lower. But if a crack be formed in the solid, reaching down to the pasty part, movement will take place in this,—just as a "creep" begins in the floor of a passage driven in a mine along a seam of coal, because the mass which acted as a counterpoise has been removed,—and so the underlying pasty material will rise in the fissure as lava. Being thus relieved from pressure and free to move, it will probably become more liquid as it ascends, until the effect of diminished pressure is counterbalanced by loss of heat. When a set of crossing fissures is formed, such as we see occurring in some districts, instead of a single one, the masses of rock bounded by them are like weights placed on the surface of a box containing such a substance as stiffening bitumen; so these will sink down, perhaps not quite equally, squeezing up the lava below. This may be the explanation of the discharges in some fissure eruptions where the molten material seems to have come up to the surface through many cracks.

We must not forget that this displacing pressure would itself affect the temperature of the mass moved, though to what extent that would be counteracted by

the relief named above we can hardly say; it would indirectly be connected with the introduction or exclusion of water, and it probably would affect any one part to a different extent at different times. In other words, as we can see from the diagrams to which we have referred, the movements of the more solid upper layers and of the lower but more plastic parts are not identical, and the one, to a certain extent, can slide upon the other. Hence the former may be becoming acutely crumpled while the latter are only gradually being deformed. Thus the plastic material at one time may be slowly changing its shape, as when a sphere is altering into an ellipsoid; at another the cessation of resistance and the opening of a vent may permit of a rapid change into some very irregular form, with all the consequent internal perturbation and molecular disturbances of the mass.

It must not be forgotten that both denudation and deposition may be, under special circumstances, disturbing factors sufficiently potent to initiate volcanic eruptions in a district hitherto at rest. The former tends to reduce the strength of the crust by the removal of solid matter, and often does this locally and unequally. Where valleys, the depth of which may be considerably over a thousand feet, are being carved in a rocky upland, every one of these becomes a line of weakness. No doubt this excavation produces a slight depression of the isotherms immediately beneath it, and thus adds to the stiffened part of the earth's crust; but this gain in strength is probably

small in comparison with the loss caused by cutting the groove. Doubtless the crust in many cases will still be proof against the strain which it endures, just as a boiler might remain sound after a few shallow notches were filed in its plates. But if these were already weak the old saying about the last ounce might hold good, and the result be an explosion with its subsequent consequences.[1]

One or two cases may be quoted to which possibly this explanation is applicable. If I am right in attributing the volcanic deposits not only of the Wrekin, the Lickey, Hartshill, and possibly Charnwood, but also of the Llanberis-Bangor district to the end of the Archæan era, that is, to an epoch just anterior to the Cambrian, these eruptions occurred when a rather extensive area of land, so far as we can infer, had existed for some time, and they were followed by one of widespread depression; in other words, they came at a period of change from upward to downward movements. The Scotch Highlands must have been profoundly affected by earth movements in post-Cambrian and pre-Devonian times; possibly twice, viz., towards the end both of the Ordovician and of the Silurian. The southern Uplands were correspondingly affected at the latter date. These upward movements, resulting in mountain-making, must have led to great denudation. Some indications of this

[1] As the *débris* from these valleys is often spread over a lowland or sea-bed very near to the foot of the hills, this process may raise the isotherm beneath that area, and, as already described, weaken the crust, so that a second zone of weakness may be produced, and the two will often not be far apart.

are found in the conglomerates of the Lower Old Red Sandstone in Scotland, a group of rocks which also bears ample evidence of contemporaneous volcanic activity on a grand scale. These disturbances continued locally even into the Carboniferous period, as they did also in England, and this period was closed by another series of earth movements, affecting much more than the whole of the present United Kingdom, and these were accompanied or succeeded by a set of sporadic volcanic outbursts.

Additional evidence may be obtained on the continent of Europe. Those post-Carboniferous disturbances were very widespread, and the breccias, and conglomerates of the lower part of the Permian in Germany indicate both extensive denudation and considerable volcanic activity. They also seem to be more or less connected with earth movements in some districts of the Alps. Here mountains, or at any rate a highland region, existed long before the making of the present chain. Great denudation went on in the Carboniferous period, which was preceded and followed by, perhaps also associated with, important disturbances of the crust. The Permian period was signalised by extensive volcanic eruptions, which probably were more widespread than is obvious at the present day, and these, in the South-eastern Alps, continued into the Trias. The genesis of the present Alpine chain was itself associated with great volcanic discharges in many parts of Europe, but as these only occur on a very limited scale in the imme-

diate neighbourhood of the mountains, they are probably the result of earth movements which have affected the stability of the crust over a large area, rather than of local denudation.

So far, then, as our present knowledge goes, we seem justified in asserting that water plays an important part in producing the explosive phenomena of volcanic eruptions, and possibly in modifying the fluidity of magmas; that the lavas, scoria, etc., discharged during such eruptions (no less than the igneous rocks which never reach the surface) represent portions of the original material of the globe, which have been only very slightly, if at all, affected by melting down any deposits of sedimentary origin; that this material, even if it has temporarily passed into a solid condition, always has been kept at a temperature not far from its melting-point; that the different types of igneous rock may be the result, in some cases, of a stratified precipitation of arrangement during the original condensation of the globe, but more often, in all probability, of some process of differentiation during later stages of its history; and lastly, that the outflow of these magmas, the intrusion of the so-called plutonic rocks, the opening out of volcanic orifices of all kinds, are primarily due to rupture of the crust, for which at present no other cause can be discovered than strains set up in consequence of the secular cooling of our planet.

It is in these directions then—the ground common to all igneous rocks, in which volcanoes and their

phenomena are only a special department—that there seems at present much to be learnt and much hope of future advances. So far as regards the ordinary physiography of volcanoes, the phenomena of eruption, the natural history, as we may call it, of their products, there seems no probability of any great advances, though there is still room for investigation on many minor points, such as the succession of minerals, and the phenomena of their development in a magma; their relation to chemical composition and environment; the nature and significance of structures such as vitreous, microlithic, crystalline, and the like; the bearing of fluid cavities on the history of a rock, and lastly the temperatures of lavas at various stages in their outflow, and while minerals are in the process of formation. These, however, though interesting and not without importance, are more of the nature of details, and the discovery of them is a matter of time and opportunity. But in regard to the great physical questions which bear upon the causes of vulcanicity, the progress which has been made of late years, though undoubtedly great, has been more in pioneering work than in constructing any complete theory. Much error has been cleared away, paths, as it were, have been hewn into the tangled thicket, the broad lines of investigation have been traced, many important facts have been ascertained. Perhaps the principal causes have been surmised, but at present we generally can affirm a fact more confidently than we can offer an explanation; and there may be some

physical principle which as yet is undiscovered, or the importance of which has hitherto been overlooked. Here then is a wide field for investigation, but the task is one of great difficulty, and requires an exceptional intellectual equipment. He who would evolve order out of our present mental chaos on this branch of the subject (including, as I have said, more than volcanic phenomena) must be at once an accomplished chemist and mineralogist, a physicist and a mathematician, a practised worker with the microscope, and a field geologist of unusually wide experience; in fact, he must, I fear, be an impossible creature, for there are questions, and this is one of them, which cannot be solved by the most diligent student of books, or by the most industrious worker in a laboratory; they demand far more toil than can be crowded into the threescore and ten years of human life. Hence the solution of these fascinating problems is more likely to come from coöperation between two or three men of first-class ability, who, after a sound preliminary training in the groundwork of the subject, have devoted themselves to a special study of the question in one of its several departments. Those among us who live to see the twenty-fifth year of the coming century are likely to be much wiser than we are now, for by that time many mists should have vanished and many difficulties have been surmounted.

GLOSSARY.[1]

Aplite: a fine-grained variety of granite, containing generally but little mica and compact in aspect.

Augite: a mineral composed of silica, magnesia, lime, and iron. Type-form a sloping prism.

Basalt: an igneous rock, compact, dark, and heavy. The majority of the lavas are either basalts or trachytes (*q.v.*).

Biotite: see *Mica*.

Bomb: lumps, generally rounded, of lava, ejected from a volcano.

Diabase: a name applied to a more or less altered variety of basalt (*q.v.*) which has assumed, often in consequence of the formation of a hydrous mineral called chlorite, a dark green tint.

Dyke: lava which has filled a fissure inclined at a high angle to the horizon, generally with sides approximately parallel.

Felspar: a group of minerals including several species, all composed of silica and alumina, with alkalies or an alkaline earth. The commonest are :— *orthoclase*, or potash felspar ; *albite*, or soda felspar ; *oligoclase*, or soda-lime felspar ; *labradorite*, or lime-soda felspar ; and *anorthite*, or lime felspar. Type-form of first a sloping prism, of the rest a prism sloping in two directions.

Ferrite: a name used for minute reddish or brownish dust, usually an iron-oxide.

Gabbro: chemically identical with basalt ; composed chiefly of a soda-lime felspar and diallage (a form of augite).

Gneiss: has the same minerals as granite (viz., quartz, felspar, and mica), but has them arranged more or less in a parallel order, so giving the rock a foliated (or leaf-like) structure, and sometimes a mineral banding.

Hematite: one of the oxides of iron, often blood-red in colour.

[1] This includes words which in some cases are used in advance of the page where their meaning is defined, or in others where the explanation could be more conveniently given (to those who needed it) in the present way. Needless to say, it is not written for experts.

Hornblende: a mineral chemically identical with augite (*q.v.*), but with some differences, structural and physical.

Hypersthene: a mineral nearly related to augite (*q.v.*), but containing little or no lime. Type-form, a rectangular prism.

Idocrase: composed of silica, alumina, lime, and some iron. Type-form a square prism.

Lapilli: the word is applied to the smaller stony masses ejected by a volcano, say from the size of a walnut downwards. *See* **Pumice** *and* **Scoria**.

Lava: Molten material poured out from a volcano. The word has no mineral connotation.

Leucite: a mineral chemically allied to orthoclase (see *Felspar*), but poorer in silica and richer in potash. Its type-form, however, is a modification of a cube; generally a twenty-four-faced figure.

Magma: a term often applied to the material of an igneous rock in a molten condition, especially when it has not yet reached the surface of the earth.

Magnetite: one of the oxides of iron, black in colour; attracted by a hand-magnet.

Melaphyre: a name formerly applied to basalts (or sometimes to unusually black augite-andesites) which were pre-Tertiary in age. The name was conferred because it was supposed that there was an essential difference between Tertiary, or later, igneous rocks and those of earlier date. It was sometimes extended to express vaguely any igneous rock which was black, compact, and not very modern. As it commemorates a serious and rather unjustifiable error, the term is better avoided.

Metamorphic: a term applied to rocks which have undergone great mineral and structural changes. Some have been originally igneous, others sedimentary.

Mica: a group of minerals characterised by splitting easily into flakes. There are several species; the most important being *biotite*, or black mica (composed of silica, alumina, magnesia, iron, and potash), and *muscovite*, or white mica (composed of silica, alumina, and potash).

Monzonite: a variety of syenite consisting mainly of the potash variety of felspar (*q.v.*) and augite, instead of the usual hornblende (*q.v.*).

Nepheline: a mineral allied to the felspar group, but with a low proportion of silica and a high one of soda. It crystallises in stumpy, six-sided prisms.

Norite: an igneous rock consisting of one of the felspars (*q.v.*) containing lime and of hypersthene (*q.v.*).

Obsidian: a volcanic glass, often dark in colour like that of a wine-bottle; chemically identical with a trachyte (*q.v.*) rich in silica.

Olivine: a mineral consisting of silica, magnesia, and iron ; occurs commonly in yellowish grains. The type-form is a rectangular prism.

Opacite: a name used for a black dust, generally magnetite (*q.v.*).

Phonolite: an igneous rock resembling a trachyte (*q.v.*), but rich in nepheline (*q.v.*).

Picrite: a crystalline rock chiefly consisting of olivine (abundant), augite (*q.v.*), and a lime felspar (*q.v.*).

Pumice: the material of trachyte (*q.v.*) or obsidian (*q.v.*), very full of cavities. It might be called glass foam. As a rule the rocks less rich in silica less frequently take a pumiceous form.

Quartz: crystallised silica. The type-form is a six-sided prism, commonly with corresponding pyramidal ends.

Scoria: an Italian word meaning dross or scum, applied to the coarsish broken material ejected by a volcano. The word has no precise connotation, but is generally applied to material less cellular than pumice, and rough in aspect, like cinders or "pulled bread." I follow the not uncommon practice of using it as a noun of multitude.

Trachyte: a compact, igneous rock, differing from basalt in a higher proportion of silica and alkalies and a lower one of magnesia and iron ; it is thus lighter and generally paler in colour.

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